Driver Understanding of the Flashing Yellow Arrow and Dynamic No Turn on Red Sign for Right Turn Applications

DRIVER UNDERSTANDING OF THE FLASHING YELLOW ARROW AND DYNAMIC NO TURN ON RED SIGN FOR RIGHT TURN APPLICATIONS

A Thesis Presented

by

ELIZABETH CASOLA

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Approved as to style and content by:

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Michael A. Knodler Jr., Chair

____
Eleni Christofa, Member

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Cole Fitzpatrick, Member

____
Richard N. Palmer, Department Head
Civil and Environmental Engineering Department

ABSTRACT

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ELIZABETH CASOLA, B.S., UNIVERSITY OF MASSACHUSETTS AMHERST
M.S.C.E., UNIVERSITY OF MASSACHUSETTS AMHERST
Directed by: Michael A. Knodler Jr.

Since their introduction to the 2009 Edition of the Manual on Uniform Traffic Control Devices, flashing yellow arrows (FYAs) have had significant success in communicating the permissive turn message. While widely used for the permissive left turn maneuver, agencies recently have been utilizing flashing yellow arrows for the use with right turn applications as drivers interact with crossing pedestrians. As pedestrian conflicts are a concern during the permissive green phase, there is additional worry for the potential interaction between a pedestrian and vehicle turning right on red. This research explores the existing driver comprehension of permissive right turns during both green and red phases through static evaluation and microsimulation. Proposed traffic devices including the FYA and the Dynamic No Turn on Red sign were evaluated in relation to the existing signal and sign conditions implemented in the field.

In comparing the proposed FYA to the existing circular green signal, the survey evaluation determined a statistically significant increase in drivers' yielding responses when interacting with the FYA as opposed to the circular green. Through application of the VISSIM program, it was determined that right turning speeds with the FYA present were significantly lower than when interacting with solely the circular green. Both the static evaluation and microsimulation determined a strong similarity between the existing circular red and R10-11 sign and the proposed dynamic no turn on red sign which verifies the strong understanding drivers have of the message and the sign itself.

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CHAPTER 1
INTRODUCTION

Millions of drivers rely on Transportation Engineers to implement and design safe and efficient roadway networks to get users from one place to another. The U.S. Department of Transportation (USDOT) recorded a nation total of 6.29 million vehicle crashes in 2015 which is a 3.8% increase from 2014 (*1*). In relation to the recorded crashes, the Institute of Transportation Engineers (ITE) has estimated that 50% of all crashes occurred at intersections and furthermore 38% of those crashes occurred at signalized intersections (*2*). Research performed by the National Highway Traffic Safety Administration (NHTSA) studies how crashes at controlled intersections were contributed to inattention, illegal maneuver, or false assumption of other users' actions (*3*). 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 the USDOT in 2015, there were 5,376 pedestrian fatalities related to traffic crashes, a 9.5% increase since 2014 (*4*).

There is an increase in pedestrians entering the roadway network as the push for healthier living continues to grow. The Commonwealth of Massachusetts has promoted walking through various health and walking that inform the public aware of various walking options as well as working to make these options more convenient and safe. Part of the Mass in Motion Wellness & Leadership Program, walk audits are conducted and policies to implement "Complete Streets" to make crosswalks safer (*5*). As a result of these programs, the number of Massachusetts residents walk as a form of commuting continues to increase. Studies show that residents of Massachusetts take on averages 4.1 trips per day; and based on subsequent surveys, walking as the mode of transportation made up 19% of those trips. As a result, from 2006 to 2017 the percent of people who walk to commute has risen from 4.2% to 4.9%. The increase in pedestrians has prompted safety plans to decrease pedestrian fatalities and hospitalizations by 20% from 2011 to 2017 (*6*).

New devices and calming features are being implemented to protect the pedestrians as they utilize the multi-modal roadway network.

Pedestrian crosswalks at signalized intersections interact with various vehicle maneuvers. These include thru movements, left turns, and right turns during a green light in addition to right turns on red in states where this action is permitted. Despite efforts to protect users via signals, movement conflicts occur. The Manual on Uniform Traffic Control Devices (MUTCD) states that when a pedestrian is permitted to walk the adjacent signal to the crosswalk must be displaying a red signal (*7*). These conflicts, which do comply with the MUTCD, include; vehicles making a left or right on green while the parallel crosswalk also has the pedestrian walk signal and a vehicle proceeding to make a right turn on red while pedestrians have the walk signal. Based on 2011-2014 Massachusetts crash data, 33.7% of intersection crashes occur as a result of vehicles making a right turn. Furthermore, of these right turn crashes, 35.6% were documented to have taken place at a signalized intersection.

1.1 Problem Statement

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 the most effective and safe indication for permissive turns over the circular green (*8*). In addition to conveying the permissive turn message, the FYA warns drivers to the possibility of pedestrians being present. The implementation of flashing yellow arrows at signalized intersections has increased over the years. While they are widely used for the permissive left turn maneuver, recently agencies have been utilizing flashing yellow arrows for the use in right turns.

As pedestrian conflicts are a concern during the permissive green phase, there is additional worry for the potential interaction between a pedestrian and vehicle turning right on red. A standard method to prevent the pedestrian and vehicle encounter is to use of the regulatory No Turn on Red (NTOR) sign which prevents the right turn on red entirely. With the intent to increase safety and efficiency of an intersection the use of a dynamic no turn on red sign is applied to protect pedestrians during their exclusive phase while allowing vehicles to turn during the permissive pedestrian phases.

1.2 Research Objectives

The focus of this research is to evaluate the effectiveness of implementing new traffic control devices at signalized intersections and the enhanced safety for vehicles, cyclists, and pedestrians as vehicles make a right turn. The application of this research has been broken down to observe right turn movements of vehicles and their interaction with crosswalks during the green and red phases at a signalized intersection.

Objective 1: Emphasize driver behavior and understanding of a flashing yellow arrow for the right turn application 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 flashing yellow arrow 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.

Objective 2: Evaluates the comprehension of 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 pedestrians phase. The first hypothesis is that drivers will have strong comprehension of this new sign, therefore reducing driver confusion at the intersection. The second hypothesis is that the dynamic no turn on red will decrease potential conflicts with pedestrians. A conflict is considered when a pedestrian is unable to cross due to the following: vehicles turning on red, a vehicle encroaching on a crosswalk while pedestrian are crossing or about to cross, and a vehicle having to suddenly break or pedestrian having to alter path to avoid collision.

1.3 Scope

The scope of this research encompasses driver’s understanding and behavior as well as effectiveness of a right flashing yellow arrow and dynamic no turn on red sign while navigating a right turn at a signalized intersection. Crash data collected from the state of Massachusetts during 2011-2014 of vehicles at a signalized intersection are referenced to highlight vehicle, pedestrian and cyclist collisions as a result of turning right. This study will focus on how permissive right turns during the green and red phase interact with the respective crosswalk’s pedestrian phases.

Current conditions consisting of the circular green and circular red and the R10-11 sign will be considered and evaluated in comparison to the new devices in the focus of this research.

CHAPTER 2
BACKGROUND

Safety of all users on the roadway is a very important facet of Transportation Engineering. The current traffic control devices provided in the Manual on Uniform Traffic Control Devices (MUTCD) provide a minimum requirement for which the devices are designed and implemented to create a safe experience for roadway users. While technology is developing so are the devices we plan to use and could increase levels of safety. The use of a flashing yellow arrow for the right turn application 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 that is making a right turn at a traffic signal would typically observe their surroundings before completing the maneuver. As this may be intuitive for drivers, they might not necessarily be looking in full to what is there. An experiment conducted by Simon and Chabris evaluated their concept of ‘inattentional blindness’ which suggests that we perceive objects that are focused on and could miss or not remember objects that were not part of that initial attention. Results conclude how users are more inclined to notice an unexpected object if it is similar to the object of the initial focus (*9*). This study confirms the worry of 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 drivers 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; which 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 (*10*).

In the instance a driver is making a right turn, there are various other maneuvers additional roadway users could be implementing. The lack of attention to these other users imposes risk which with the use of traffic features could alleviate. A study done at the University of South Florida observes how right turning drivers comply to new pedestrian features in the form of "STOP HERE ON RED," "NO TURN ON RED," "TURNING VEHICLES YIELD TO PEDESTRIANS," and "RIGHT ON RED ARROW AFTER STOP" signs. Researchers compared if drivers abided by restrictions before and after these pedestrian features were implemented; and results proved the utilization of these features did in fact increase compliance, and even more so when pedestrians were present, making drivers more aware of their surroundings(*11*).

2.2 Right Turn on Red (RTOR)

The policy of Right Turn on Red was first adopted in 1937 by the state of California (*12*). The concept of this maneuver allows vehicles at a red light traffic signal to safely proceed to turn right when clear to help reduce delay and increase intersection capacity. Various intersections utilize the ability for vehicles to turn right during a red light. While the legality of right turns on red is state regulated, the implementation for this action is determined depending on the intersections conditions. With the guidance of the Manual on Uniform Traffic Control Device (MUTCD), Transportation Engineer use engineering judgement to determine which intersections should allow the right on red maneuver or prohibit it. The use of a No Turn on Red Sign is used when at least one of six safety conditions are met as defined in the MUTCD:

1. Inadequate sight distance to vehicles approaching from the left (or right, if applicable)
2. Geometrics or operational characteristics of the intersection that might result in unexpected conflicts

3. An exclusive pedestrian phase
4. An unacceptable number of pedestrian conflicts with right-turn-on-red maneuvers, especially involving children, older pedestrians, or persons with disabilities
5. More than three right-turn-on-red accidents reported in a 12-month period for the particular approach
6. The skew angle of the intersecting roadways creates difficulty for drivers to see traffic approaching from their left (*7*).

The addition of the right turn on red increases the volume of drivers that are able to transverse an intersection, while leaving pedestrians and bicyclists more vulnerable to vehicle conflict. In the states of New York, Ohio, and Wisconsin a study observed pedestrian and bicycle crashes with right turning vehicles for 12 months prior and following the adoption of the right turn on red (RTOR). It was determined that crashes involving pedestrians increased from 1.47% to 2.28%, and bicyclists increased from 1.40% to 2.79% (*13*). 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, 95% of drivers that 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 stop at all before entering the intersection (*14*). Research that has been done by Yan and Richards show how sight distance affects drivers' behavior while planning to make a right turn on red. They concluded that due to limited sight drivers tend to inch forward to increase visibility. As a result of this action, drivers encroach on crosswalks which increase the possibility of pedestrian and bicycle conflicts and delay for crosswalk users (*15*).

2.3 Methods

A beneficial tool for analysis is the pairing of static survey and simulation. These methods safely test users understanding and behavior and if both the knowledge and application correctly correspond. The initial use of the survey generates the basis of understanding for the participant being exposed to a new device. An evaluation of flashing yellow arrows performed in Indiana provided survey participants with the ability to decide which action would be taken when shown images of turning scenarios; ‘go, yield, or stop.’ This basic approach allowed these researchers to observe if the survey responses were or were not fail-critical based on the maneuver that would’ve been performed. This study defines fail-critical to be a response where if implemented behind the wheel would lead to a collision, including stopping at a green signal and proceeding at a red (*16*). Similarly, a survey performed in Florida in the form of open-ended and multiple choice questions to assess the comprehension of a flashing pedestrian indicator (FPI) message and what action would be taken if turning right in response to seeing an FPI. The use of this survey emphasized public reaction, opinion, and concern while asking for feedback and impressions. This direct communication with the users provides contributing input for continuing research and the success and safety of the design (*17*).

To conclude if a new traffic design is safe and practical for implementation, microsimulation models can assess and compare roadway conditions. The combination of microsimulation with safety analysis is a technique used by many researchers to evaluate roadway networks preemptive to the high levels of crash occurring. Surrogate Safety Assessment Model (SSAM) uses VISSIM model trajectory outputs to classify safety factors including decelerating rate, event type, and conflict identification *(18)*. Research performed at Southeast University determined models performed in VISSIM and the conflicts identified in SSAM were in fact valid representations of the observed conditions in the field. Through modeling and calibration the goodness-of-fit between simulation and observed conflicts and performance prediction were reasonable *(19)*. The validity of using SSAM to identify conflict provides safety judgement was tested through the Federal Highway Administration by evaluating theoretical and field tests. The theoretical tests determined if SSAM can determine behaviors at various intersections designs. The field test compares the output data at specific intersections from SSAM to the actual crash data. It was determined that the data provided by SSAM was significantly correlated to field data and could accurately decipher between vehicle conflict types and frequency *(20)*. Microsimulation and safety analysis are used to provide adequate motivation to further test roadway conditions with subjects.

While SSAM has begun the beginning phases by the Federal Highway Administration (FHWA) for determining pedestrian behavior and conflicts, the process and components required have not been validated. The FHWA states that an approach to consider for weeding out pedestrian conflicts is the filter the max speed to less than five miles per hour based on pedestrian pace, yet this method has been observed to have errors and invalid responses (*21*). The Center for Advanced Transportation Systems Simulation at the University of Central Florida began to examine the feasibility of confirming pedestrian- vehicle conflicts through the inputs required for using SSAM. Seven signalized intersections were observed and recorded to review for pedestrian and vehicle conflicts. These seven intersections were input into VISSIM to the specifications that were found in the field. The trajectory outputs from a calibrated VISSIM model were then used in SSAM. The suitable maximum time to collision (TTC) and post-encroachment time (PET) were tested to create a SSAM output that matches the field data with the lowest mean absolute percent error (MAPE). It was determined that the maximum TTC and PET values to recreate the observed pedestrian collisions were 2.7 and 8, respectively (*22*).

2.4 Flashing Yellow Arrows

The MUTCD states the flashing yellow arrow 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 mention that if the permissive flashing yellow arrow is sharing a signal face only one other circular signal (steady red, steady yellow or steady green) must be displayed at the same time. When the yellow arrow is added to a signal it provides drivers with a warning message, as the MUTCD defines yellow as a warning color, to check surroundings prior to performing intended maneuver (*7*). 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 the arrows were pointed. This demonstrates how the presence of flashing arrow cues our attention and automatically orients gaze to the provided direction (*23*). The use of the arrow aligns 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 flashing yellow arrow 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 a flashing yellow arrow for the left turn application was the best alternative for the circular green and easily understood (*8*). Through NCHRP research performed by Dr. Knodler, et al. flashing yellow arrows for left turn applications were observed and tested through surveys and driving simulator. Results yielded during the driving simulator that over 85% of drivers performed the correct response, yield or stop first, when interacting with the flashing yellow arrow. Furthermore, for the independent survey and simulator follow-up survey the correct yield or stop first responses collected were determined to be statistically significant for the simultaneous circular green and flashing yellow arrow display. It was concluded from this research that driver comprehension of the permissive flashing yellow arrow was consistent with previous research supporting the use of the FYA (*24*).

With such success of the flashing yellow arrow for permissive left turns, right turns are now being evaluated for this device for turns competing with pedestrians crossing. Boot et al. at the South Florida University studied the use of a flashing pedestrian indicator (FPI) which the flashes a right yellow arrow alternating with a pedestrian walk indicator to warn drivers of a conflicting pedestrian presence. Through the use of static survey, respondents understood the intention of the FPI which minimized risk to pedestrian. Those who participated in the driver judgement study, to analyze reaction time and accuracy, made slower decisions at an intersection with the FPI as they were cautious and searching of pedestrians (*17*).

2.5 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; they must yield to the right of way to pedestrians lawfully within the intersection of adjacent crosswalk during that signal phase (*25*). 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. defines the pedestrian conflict as the crossing being compromised, resulting in the delay of the pedestrian, having to alter travel path, or 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, it was derived that there was an average right turn volume of 3.6 vehicles to pass during the pedestrian signal (*26*). Compromised pedestrian paths were also considered from the aspect of vehicles turning right on red. Conducted by the ITE Technical Council Committee 4M-20 over 120 days at 50 different intersections, studies show that 28.6% of pedestrians that we present during a right turn on red maneuver had to yield to the vehicle making the right turn (*14*).

CHAPTER 3
STUDY DESIGN

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

3.1 Literature Review

The initial phase of this thesis research will be performing a literature review. Research done on each component of this research will be studied to compare methodologies and results. Emphasis on this literature review is to determine the behavior of pedestrians and drivers at intersections and at the intersection conditions in question (flashing yellow arrow and right turn on red). This task has been ongoing throughout this research to best comprehend and address previous research and their impact.

3.2 Crash Data

The crash data that is to be analyzed will be acquired from the University of Massachusetts Transportation Center (UMTC). Through the UMTC, the UMass Safe: Traffic Safety Research Program stores all safety data, including crashes, in the Safety Data Warehouse (*27*) which is where the crash information will be extracted. The conditions or attributes that will be compiled for each individual crash are the Crash Number, Date, Time, Injury Status, Roadway Intersection Type, Trafficway Description, Traffic Control Device Type, First Harmful Event, First Harmful Event Location, Manner of Collision, Weather Condition, Light Condition, Road Surface, Speed Limit, Vehicle Unit Number, and Sequence of Events and Most Harmful Event Codes. To minimize the data to be sorted, the parameters for extraction were based on years 2011 through 2014 and crashes occurring only at an intersection. A Structured Query Language (SQL) code, as seen in the Appendix, was developed to input in the Safety Data Warehouse to call each attribute along with the specific crash which is presented in a table to easily be transferred into Microsoft Excel.

While this code provides plenty of information, the crash coordinates are a key component that is acquired through the Massachusetts Department of Transportation's Crash Portal (*28*). In this database, there are multiple options to pick how to view and locate crashes and the method used was the AdHoc Query Tool. This option, similar to UMass Safe, provides choices for specific attributes to collect as well as utilizes the date parameter. The attributes used for this extraction were Crash Number, X Coordinate, and Y Coordinate. After all the crashes for 2011-2014 were exported to an Excel file, the two crash sheets are to be merged. With the use of Microsoft Access, the two Excel files were liked by the specific incident Crash Number which added a location to each crash being observed. Through Access, any piece of data that did not have corresponding coordinates had been removed from the resulting list. The new master file was then exported to Excel by year for further GIS analysis.

Before creating a GIS crash map, data layers representing the state of Massachusetts were imported from MassGIS (*29*) and consisted of shapefiles Counties_poly.shp, NEMASK_ARC.shp, OCEANMASK_POLY.shp, outline 1.shp and EOTMAJROADS_ARC.shp to develop the base of the map to be evaluated. Once the base of the map was added into the new worksheet, the crashes were added by their X and Y coordinates which were assigned to each crash that was gathered in Excel, and plotted corresponding points on the map of Massachusetts. This input took place for each year's Excel file. As each sheet was added as a layer on the map, the layers were exported to a Shapefile to allow the access of the attributes information. The extracted attributes and the corresponding code values can be found in Error! Reference source n ot found..

The map consists of four shapefile layers that contain the crashes data for each year of observation. While each year will be looked at individually, all years were merged into one shapefile to analyze as one population. This merge allowed each year's data to be input while keeping all corresponding attributes with one single output. With five final crash layers created (2011-2014, 2011, 2012, 2013, and 2014) attribute extraction took place on each layer exactly the same way.

The first piece of information to be gathered was the amount of right turn crashes recorded for each layer. To find this data, the select by attribute function was utilized with the SQL of Vehicle Action Prior to Crash is a Right Turn which would be written as: "VEHC_MANR_ACT_CODE"= 3. With these points selected, Create Layer from Selected Features will export the right turn crashes to its own layer, resulting in four more layers added to the table of contents.

Working with the Right Turn layers created (RT_11-14, RT_2011, RT_2012, RT_2013, and RT_2014) the next selection will determine how many crashes occurred at signalized intersections. Using the Select by Attribute feature an SQL to call out the Traffic Control Device Type to be a Traffic control signal the code would read: "TRAF_CNTRL_DEVC_TYPE_CODE" = 3. These selections were then exported to a new layer using Create Layer from Selected Features tool (with new layers names to for easy recognition; RT_TfSgn_2011-2014, RT_TfSgn_2011, RT_TfSgn_2012, RT_TfSgn_2013, and RT_TfSgn_2014). Now working with the Right Turn layers (RT_11-14, RT_2011, RT_2012, RT_2013, and RT_2014) the next selection will determine how many crashes occurred at signalized intersections. Using the Select by Attribute feature an SQL to call out the Traffic Control Device Type to be a Traffic control signal the code would read: "TRAF_CNTRL_DEVC_TYPE_CODE" = 3.

Table 1: Accident Attribute Codes

INJY_STAT_DESCR	RDWY_JNCT_TYPE_CODE	TRAFY_DESCR_CODE	TRAF_CNTRL_DEVC_TYPE_CODE	FIRST_HRMF_EVENT_CODE
1 Fatal	1 Not at intersection	1 Two-way, not divided	1 No controls	1 Collision with motor vehicle in transport
2 Non-Fatal Injury Incapacitating	2 Four-way intersection	2 Two-way, divided, unprotected median	2 Stop signs	2 Collision with parked motor vehicle
3 Non-Fatal Injury Non-incapacitating	3 T-intersection	3 Two-way, divided, positive median barrier	3 Traffic control signal	3 Collision with pedestrian
4 Non-Fatal Injury Possible	4 Y-intersection	4 One-way, not divided	4 Flashing traffic control signal	4 Collision with cyclist
5 No injury	5 On ramp	99 Unknown	5 Yield sign	5 Collision with animal- deer
99 Unknown	6 Off ramp	**WEATH_COND_CODE_1**	6 School zone sign	6 Collision with animal- other
FIRST_HRMF_EVENT_LOC_CODE	7 Traffic circle	1 Clear	7 Warning signs	7 Collision with moped
1 Roadway	8 Five-point or more	2 Cloudy	8 Railroad crossing device	8 Collision with work zone maintenance equipment
2 Median	9 Driveway	3 Rain	99 Unknown	9 Collision with railway vehicle
3 Roadside	10 Railway grade crossing	4 Snow	**VEHC_MANR_ACT_CODE**	10 Collision with other movable object
4 Shoulder - paved	99 Unknown	5 Sleet, hail, freezing rain	1 Traveling straight ahead	20 Collision with curb
5 Shoulder - unpaved	**MANR_COLL_CODE**	6 Fog, smog, smoke	2 Slowing or stopped	21 Collision with tree
6 Shoulder- travel lane	1 Single vehicle crash	7 Severe crosswinds	3 Turning right	22 Collision with utility pole
7 Outside roadway	2 Rear- end	8 Blowing sand, snow	4 Turning left	23 Collision with light pole or other post
99 Unknown	3 Angle	97 Other	5 Changing lanes	24 Collision with guardrail
ROAD_SURF_COND_CODE	4 Sideswipe, same direction	99 Unknown	6 Entering traffic lane	25 Collision with median barrier
1 Dry	5 Sideswipe, opposite direction	**AMBNT_LIGHT_CODE**	7 Leaving traffic lane	26 Collision with ditch
2 Wet	6 Head on	1 Daylight	8 Making U-turn	27 Collision with embankment
3 Snow	7 Rear to rear	2 Dawn	9 Overtaking/ passing	28 Collision with bridge
4 Ice	99 Unknown	3 Dusk	10 Backing	29 Collision with bridge overhead structure
5 Sand, mud, dirt, oil, gravel	**Injury Status**	4 Dark- lighted roadway	11 Parking	30 Collision with unknown
6 Water (standing, moving)	Injury	5 Dark- roadway not lighted	97 Other	40 Non-Collision Overturn/rollover
7 Slush	PDO (Property damage only)	6 Dark- unknown roadway lighting	99 Unknown	41 Non-Collision jackknife
97 Other	Unknown	97 Other		42 Non-Collision other non-collision
99 Unknown		99 Unknown		43 Non-Collision unknown non-collision
				97 other
				99 unknown

These selections were then exported to a new layer using Create Layer from Selected Features tool (RT_TfSgn_2011-2014, RT_TfSgn_2011, RT_TfSgn_2012, RT_TfSgn_2013, and RT_TfSgn_2014). Further investigation of crash information was done on all ten layers. The Select by Attribute was used with the following SQL to create crash statistics:

“INJY_STAT_DESCR” = 1 (Injury Status = Fatal)

“INJY_STAT_DESCR” = 2 (Injury Status = Non-Fatal Injury Incapacitating)

“INJY_STAT_DESCR” = 3 (Injury Status = Non-Fatal Injury Non-incapacitating

“INJY_STAT_DESCR” = 4 (Injury Status = Non-Fatal Injury Possible)

“FIRST_HRMF_EVENT_CODE” = 3 (First Harmful Event = Collision with pedestrian)

“FIRST_HRMF_EVENT_CODE” = 4 (First Harmful Event = Collision with cyclist)

The values acquired were recorded and converted into percentiles for statistical use in this research.

3.3 Survey

The intended purpose of creating the survey is to best gather and evaluate responses in the aspect of both behavior and situational understanding based on provided scenarios. Due to the objective of this research, this static evaluation will portray 9 scenarios to compare the responses of existing conditions to the proposed devices being observed as seen in **Table 2.**

Through the use of the Paint application the traffic signals were created representing the circular green, circular green with a right yellow arrow, and the circular red. To represent the right yellow arrow as flashing in the survey a GIF maker website (http://gifmaker.me/) was used. This site prompted the upload of two images, the four signal head with just a circular green and the four signal head with the right yellow arrow above the circular green. Inputting the settings of 500 milliseconds animation flashing speed and repeat set to infinite loop this image was downloaded as a .gif file that would play the signal with the yellow arrow flashing. In addition to the signals, the R10-11 sign and the Dynamic No Turn on Red images were accessed from the Federal Highway Administration (*30*) and like the signals cropped onto an intersection backdrop.

Table 2: Nine Survey Scenarios in Question

	Right Turn Permissive Display	Pedestrian Present
Existing	Circular Green Ball	Yes No
	Circular Red Ball	Yes No
	R10-11 "No Turn of 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

The intersection portrayed in the scenarios, consists of a parallel and 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 in 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 1.**

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," along with a participation agreement before continuing. 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). 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 statement with responses are as seen in **Table 3.**

Table 3: 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.

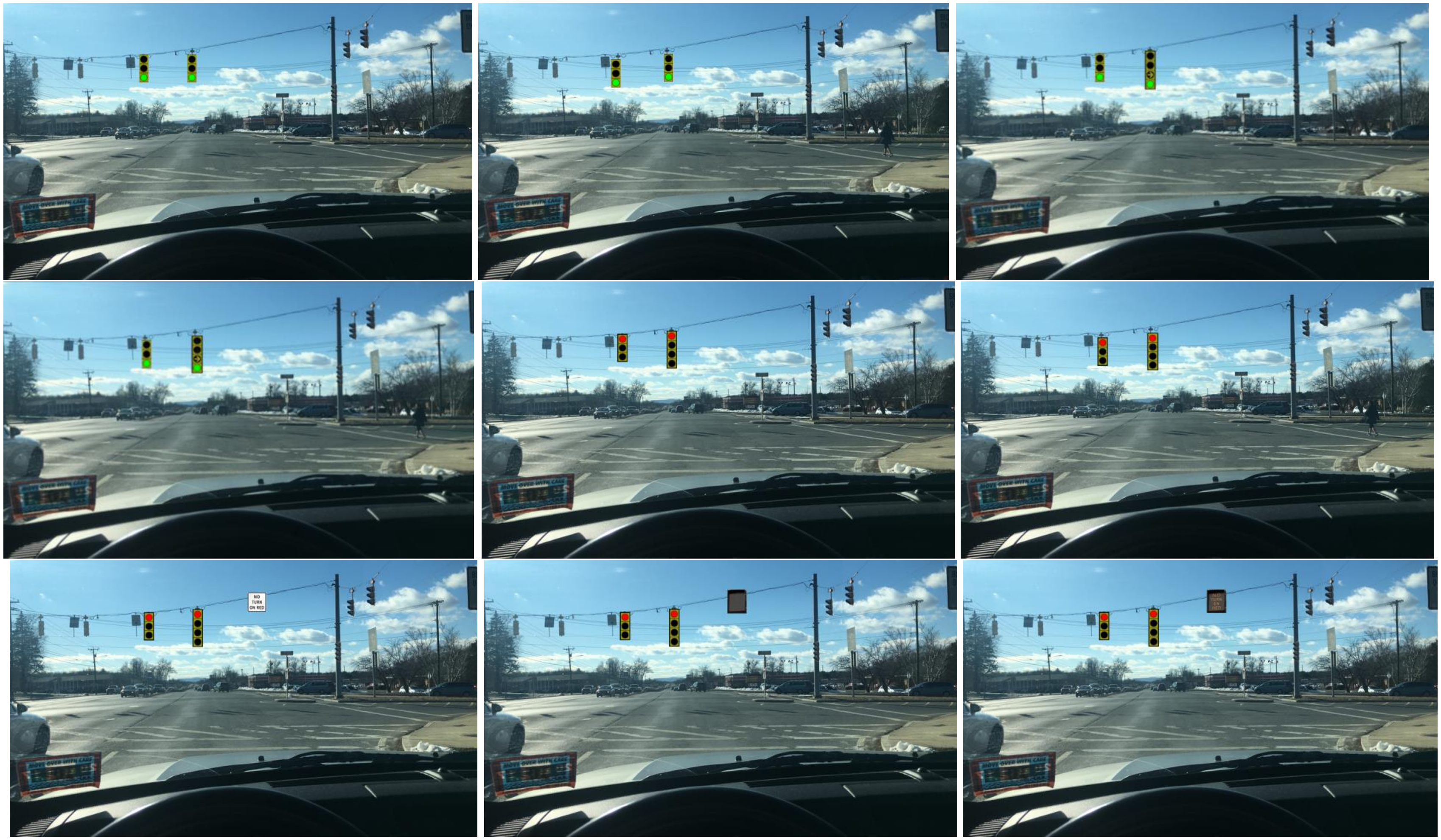

Figure 1: The Nine Images Used to Depict the Survey Scenarios

In the event that the respondent selected the ‘Pedestrian likely present’ option, the Logit function built into Survey Monkey would enable a follow-up question, before being shown 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 2**. The respondents are 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.” After the respondent answers all 9 scenarios and the possible follow-up questions the survey completes and the responses are stored. At 200 responses the data was analyzed and a bar graph was formulated for all the traffic signal scenarios, the right turn on red scenarios, and the crosswalk location options. These graphs represent the percent (Y-axis) of each response (X-axis) for every situation portrayed.

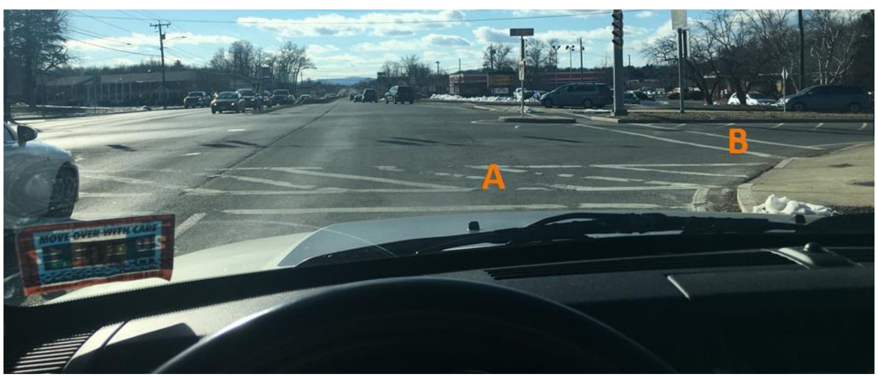

Figure 2: Crosswalk Image Used in Survey to Determine Pedestrian Location

3.4 Chi^2 Statistical Test

The use of the Chi^2 statistical test was performed on various results of the static evaluation due to the categorical nature of the survey; comparing two devices with their various response options for each device. This was done to determine the statistical significance in comparing 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 include circular green vs. flashing yellow arrow and circular green with pedestrian vs. flashing yellow arrow with pedestrian.

Using Excel, p-values were calculated for each response option in terms of their respective signal scenario. 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 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.

3.5 Microsimulation

The use of microsimulation was executed with the intent to assess the proposed devices applied to a particular intersection. This microsimulation was created in the program PTV VISSIM. This program allows for the observation of free flow simulations with the ability to apply particular design components. The intersection to be recreated in VISSIM can be located in Amherst, Massachusetts at University Drive and Route 9, as seen in **Figure 3**, the same intersection represented in the static survey section of the research. At this intersection Route 9 (Northampton Road) consists of two thru lanes in both directions with a left turning pocket lane in the east bound direction. University Drive and Snell Street have one thru lane along with one left turning lane. Each approach has the ability for right turn on red and crosswalks are located on University Drive, Snell Street, and Route 9 on the eastern side of the intersection. With the base map of the area provided, each leg of the intersections was input into VISSIM with the appropriate number of lanes, lane width, and speed. Each leg was made up of a link and was connected with its proper maneuver from a given lane with the use of connector links. Conflict areas were defined for each turning movement's right of way. Traffic data was collected on April 8th, 2017 between 4pm and 6pm with a peak hour determine to be 4:30 through 5:30pm. With this data, the vehicle leg volume inputs and vehicle compositions based on percent of heavy vehicles were defined. The vehicle routes were defined and used the relative flow to decipher the number of vehicles making that movement based on the total leg vehicle input. Links were created on University Drive, Snell Street, and Route 9 on the east most side and defined as pedestrian areas resulting in crosswalks. Like the intersection pedestrian volumes and routes were added to the crosswalks along with the zebra pavement markings.

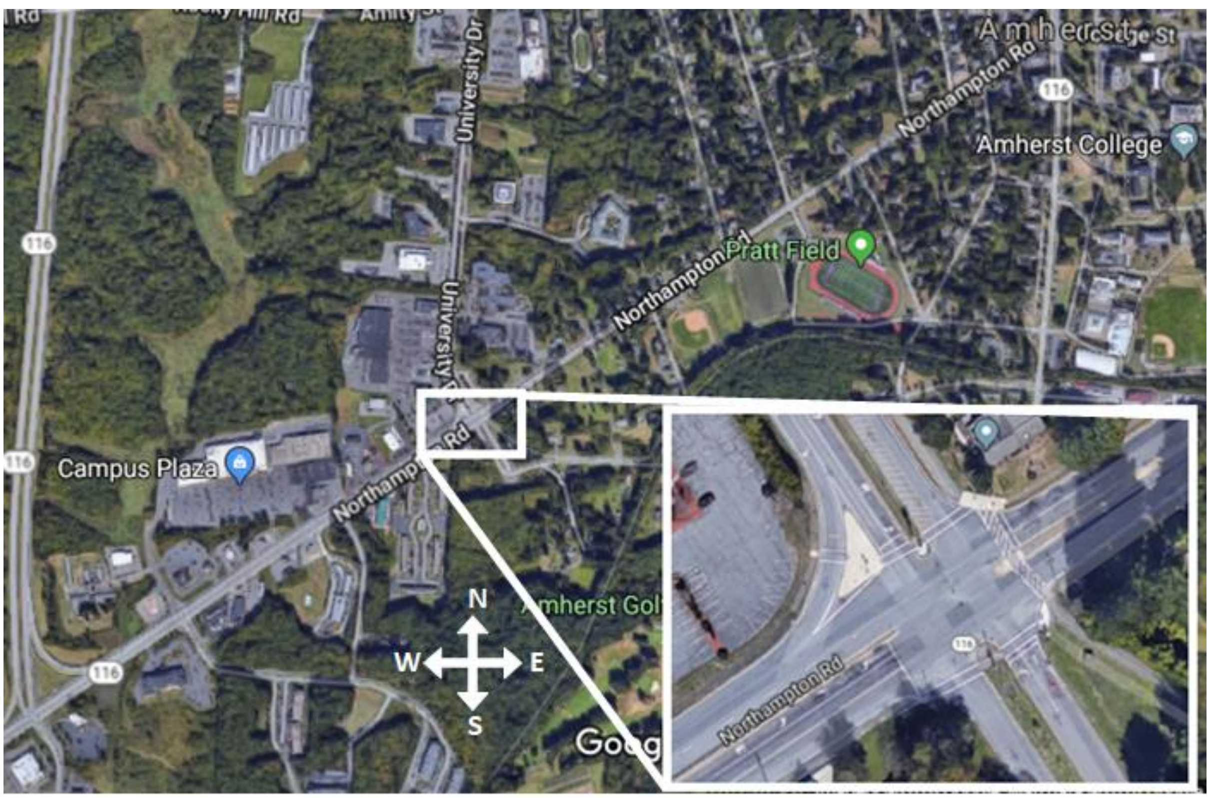

Figure 3: Intersection Location in Amherst Massachusetts

Signal timings were provided by the state department of transportation and utilized in the VISSIM simulation. The existing signals in the field are actuated signals yet it was assumed that during the peak hour each phase would be maxed out therefore the max timing were used to implement fixed timings. The green, yellow, and all red timing were input for each phase of the signals as well as the pedestrian timings. The vehicle signal timings in seconds used can be seen in **Table 4** and pedestrian crossing time can be seen in **Table 5**. The phasing sequence is represented in **Figure 4**. A single signal program was created for this intersection and a signal group represented each leg's phase. Signal heads were added to each lane of the simulated intersection with its corresponding signal phase. Stop signs for each lane where a right turn is available were added and linked to the respective signal phase to allow right turn on red.

Table 4: Signal Phasing at University Drive and Route 9 Intersection

	Route 9 Eastbound Left Turn	Route 9 Eastbound	Route 9 Westboun d	Universit y Drive	Snell Stree t
Phase	5	2	6	4	8
Green Time	20	30	45	25	15
Yellow Clearance	4	4	4	4	4
All Red	2	2	2	2	2

Table 5: Pedestrian Phasing At University Drive and Route 9 Intersection

	Route 9 East	University Drive	Snell Street
Active During Signal Phase	8	6	2
Walk	5	5	5
Flashing Don't Walk	20	26	23

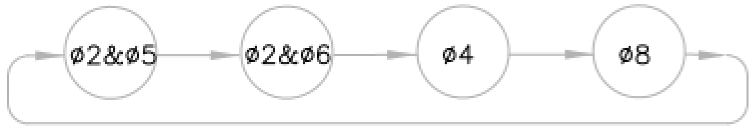

Figure 4: Signal Diagram for University Drive and Route 9 Intersection Phasing

Once the base conditions were represented and the simulation ran calibrations were performed before alterations were made for the proposed conditions. Calibrating this model compared volumes of each leg over ten various simulation runs based on the Federal Highways Administration's (FHWA) Traffic Analysis Toolbox. The volume parameters implemented by the FHWA were based on freeway model calibration targets by Wisconsin DOT which can be seen in **Table** 6 (*31*). When the parameters were met for links containing less than 700 vehicles per hour and the model is considered calibrated, adjustments on the intersection were made to represent the proposed intersection devices.

The first proposed scenario that was created was the flashing right yellow arrow. The links, vehicle and pedestrian inputs, and signal phases remained the same as the existing conditions that made up the intersection. To incorporate the flashing yellow arrow additional signal groups were added to the signal phasing program. A signal group was created for the three flashing yellow arrows that are to be added into the system at each Route 9 approach and Snell Street. For each individual yellow arrow phase, the timing was set to have the flashing yellow mirror the respective green time. A signal head is placed at the right most lane for the three approaches in addition to the existing green signal and set to the shape of a right arrow. To represent the dynamic no turn on red conditions, adjustments are made to allow the ability to or not be able to make a right turn on red. The existing condition intersection first created as a baseline included the right turn on red component. This scenario will also be used to represent the deactivated dynamic no turn on red which allows vehicles to make that turn. To represent the activated dynamic no turn on red, the stop signs that are linked to the red signal of a given link were removed to prevent right turn on red altogether.

Table 6: Wisconsin DOT Microsimulation Calibration Targets Utilized by the FHWA

MOE Criteria	Calibration Acceptance Targets
Hourly Flows, Model versus Observed	
Individual Link Flows	
< 700 veh/hr	Within 100 veh/hr of Field flow for > 85% of cases
700 to 2,700 veh/hr	Within 15% of Field flow for > 85% of cases
> 2,700 veh/hr	Within 400 veh/hr of Field flow for > 85% of cases
Sum of all link flows	Within 5% of sum of all link counts
GEH Statistic* for individual link flows	GEH < 5 for > 85% of cases
GEH Statistic for sum of all link flows	GEH < 4 for sum of all link counts
Travel Times, Model versus Observed	
Journey Times, Network	Within 15% (or 1 min, if higher) of > 85% of cases
Visual Audits	
Individual Link Speeds	Visually acceptable speed-flow relationship to analyst's satisfaction
Bottlenecks	Visually acceptable queuing to analyst's satisfaction

The simulation was run with the following parameters: 10 runs, a random seed of 42 and a seed increment of 1. The data measurement collection was activated to collect various attributes for each individual run at each leg of the intersection. A speed comparison was performed against the existing conditions and the proposed flashing yellow arrow condition. Due to all conditions except the addition of the flashing yellow arrow remaining the same the average harmonic speed for the intersection was analyzed over the ten runs. Increases in pedestrians (5 times and 10 times the base condition) were explored for additional consideration. Statistical tested was performed in the form of a T-test against each existing and proposed condition through a t-test online calculator (*32*). The collection of trajectory files was also activated in VISSIM for future analysis in Surrogate Safety Assessment Model (SSAM). The SSAM software allows the input of VISSIM trajectory files to be assessed for possible conflicts. The maximum time to collision (TTC) was set to 2.7 and the maximum post encroachment time (PET) was set to 8 based of research done at the University of Central Florida. The conflicts detected were compiled with various attributes for investigation.

CHAPTER 4
RESULTS

The results of this research were found to be consistent with the objective of this research. The outcomes gathered have been broken down in the sections below.

4.1 Crash Data

The crashes collected provided raw data to further be analyzed. From 2011- 2014 in the Commonwealth of Massachusetts there were 486,692 crashes at an intersection, fully documented with X and Y coordinates and other contributing information input into ArcGIS. Of these crashes, 16,432 were a result of the vehicle making a right turn prior to crash and 5,854 of those right turn crashes occurred at a signalized intersections. The statistical and observed data of crashes at intersections while vehicles are making a right turn can be found in

Table 7.

Right turn crashes at a signalized intersection makes up 35.63% of all right turn crashes. A simple right turn maneuver seems trivial; a little over 1,000 people have been injured where three of the injuries were fatal and 83 were incapacitating. Data shows there is a consistent trend in the percentage of those injured due to crashes of this manner. There were 17.83% of crashes resulting in injury over the four year period, furthermore the injury status for 2011, 2012, 2013, and 2014 were 17.05%, 18.42%, 17.88%, and 17.96% respectively.

Due to the many types of roadway users, not only vehicle users are at risk of injury. At a signalized intersection over 200 vehicles collided with pedestrians and over 200 vehicles collided with cyclists in the event of making a right turn. Again, the data confirm a consistent range, from 3-5%, of pedestrian and cyclist collisions over the four year span. In 2011 there were 50 pedestrians and 54 cyclists involved in an accident as a result of right turning vehicles;

subsequently, in 2012 there were 54 pedestrians and 68 cyclists, in 2013 there were 55 pedestrians and 50 cyclists, and in 2014 there were 65 pedestrians and 76 cyclists.

The Commonwealth of Massachusetts Motor Vehicle Crash Report provides responding officers with the ability to record the surrounding condition to further grasp possible cause of the incident. Exploratory analysis on weather, lighting, and surface conditions were done to find the most significant setting when the observed crashes had taken place. Over the four year period 4,108 out of the 5,854 crashes occurred while weather conditions were clear. Subsequently, 4,239 of crashes occurred during the daylight and 4,525 when the road surfaces were dry. It was expected to find low percentages of crash statistics related to right turns at signalized intersections. However, this data verified there is a strong consistency over time of each crash condition as well as location.

Table 7: Crash Data Results in the Years 2011-2014

Year	2011-2014		2011		2012		2013		2014	
Total Right Turn Crashes at All Intersections	16432		4111		4014		3974		4333	
	Count	***Percent***	***Count***	***Percent***	***Count***	***Percent***	***Count***	***Percent***	***Count***	***Percent***
Total Right Turn Crashes at Signalized Intersections	5854	35.63%	1443	35.10%	1493	37.19%	1342	33.77%	1576	36.37%
Collision with Pedestrian	215	3.67%	50	3.47%	54	3.62%	55	4.10%	65	4.12%
Collision with Cyclist	248	4.24%	54	3.74%	68	4.55%	50	3.73%	76	4.82%
Collision with Motor Vehicle in Traffic	4485	76.61%	1142	79.14%	1156	77.43%	1003	74.74%	1184	75.13%
Fatality	3	0.05%	1	0.07%	0	0.00%	1	0.07%	1	0.06%
Incapacitating	83	1.42%	18	1.25%	28	1.88%	23	1.71%	14	0.89%
Non-incapacitating	438	7.48%	110	7.62%	118	7.90%	98	7.30%	112	7.11%
Injury possible	520	8.88%	117	8.11%	129	8.64%	118	8.79%	156	9.90%
Property Damage Only	4560	77.90%	1148	79.56%	1133	75.89%	1044	77.79%	1235	78.36%
Daylight	4239	72.41%	1030	71.38%	1079	72.27%	928	69.15%	1148	72.84%
Clear Day	4108	70.17%	990	68.61%	1071	71.73%	949	70.72%	1098	69.67%
Dry Surface	4525	77.30%	1062	73.60%	1193	79.91%	1071	79.81%	1199	76.08%

4.2 Survey

In the spring of 2017, this static survey collected 200 anonymous responses of subjects in the Northeast region of the United States. 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 of this, all responses were analyzed as a general population. Further, the driving experience of the received responses consisted of 9.5% having less than five years, 35.5% having five to nine years and 55% having over ten years. There was no statistical difference in the remainder of the demographic information.

Between the circular green indication to the right FYA the responses lessened for ‘Right turn permitted’ from 93% to 89% and ‘Driver has the right of way’ from 43% to 32%. There was minimal variation in 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%) as well as ‘Stop and wait for alternate signal’ (1.5% to 3.8%). For both non-pedestrian and pedestrian scenarios the response rates from circular green to right FYA increase from 24% to 57% and 35% to 69%, respectively. The full breakdown of results can be seen in

.

Table 8: Compiled Results for the Nine Survey Scenarios in Question

Answer Options	Circular Green	Circular Green + Pedestrian	Right Flashing Yellow Arrow	Right Flashing Yellow Arrow + Pedestrian
Pedestrians likely present	53.10%	--	50.80%	--
Right turn permitted	93.30%	88.90%	88.50%	89.10%
Driver has the right of way	43.80%	14.20%	32.80%	15.50%
Pedestrian has the right of way	48.50%	86.30%	47.00%	84.50%
Must complete stop at stop line before proceeding	11.90%	13.70%	11.50%	11.50%
Proceed through intersection if clear	82.50%	72.60%	66.70%	69.00%
Yield before entering intersection	24.70%	35.80%	57.40%	69.00%
Stop and wait for an alternate signal	1.50%	1.10%	3.80%	4.00%
None of the above	0.00%	1.10%	0.50%	0.60%
Crosswalk A	5.80%	--	1.10%	--
Crosswalk B	57.30%	--	60.20%	--
Both A and B	36.90%	--	38.70%	--

Answer Options	Circular Red	Circular Red + Pedestrian	Original No Turn On Red Sign	Dynamic No Turn On Red Off	Dynamic No Turn On Red On
Pedestrians likely present	44.70%	--	42.10%	42.20%	43.00%
Right turn permitted	68.20%	71.40%	5.50%	80.70%	7.00%
Driver has the right of way	4.70%	3.60%	1.20%	7.50%	4.40%
Pedestrian has the right of way	54.70%	88.70%	45.70%	52.80%	50.60%
Must complete stop at stop line before proceeding	84.10%	85.70%	22.60%	84.50%	24.10%
Proceed through intersection if clear	33.50%	38.10%	0.60%	43.50%	3.80%
Yield before entering intersection	22.40%	30.40%	3.00%	29.20%	3.80%
Stop and wait for an alternate signal	30.60%	29.20%	90.90%	22.40%	89.20%
None of the above	0.60%	0.00%	4.90%	0.60%	4.40%
Crosswalk A	48.00%	--	31.60%	42.00%	29.70%
Crosswalk B	5.30%	--	5.30%	8.70%	6.80%
Both A and B	46.70%	--	63.20%	49.30%	63.50%

Based on the Chi^2 statistical test performed on all response variables as seen in **Table 9,** there was only a significant difference found in the 'Yield before entering intersection' response from the circular green to 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 5.** A further breakdown of the results by individual signal scenario can be seen in **Figure 6**, **Figure 7**, **Figure 8**, **Figure 9**, and Error! Reference source not found.. Similarly for the permissive phase and right FYA scenarios, respondents acknowledged the likelihood of a pedestrian presence 53% to 51%, respectively. 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 flashing yellow arrow was introduced as displayed in **.** A large percentage (36.9% at circular green and 38.7% at FYA) observed there could be pedestrians present to use both crosswalk A and B.

Table 9: Breakdown of Chi^2 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-value considered statistically significant

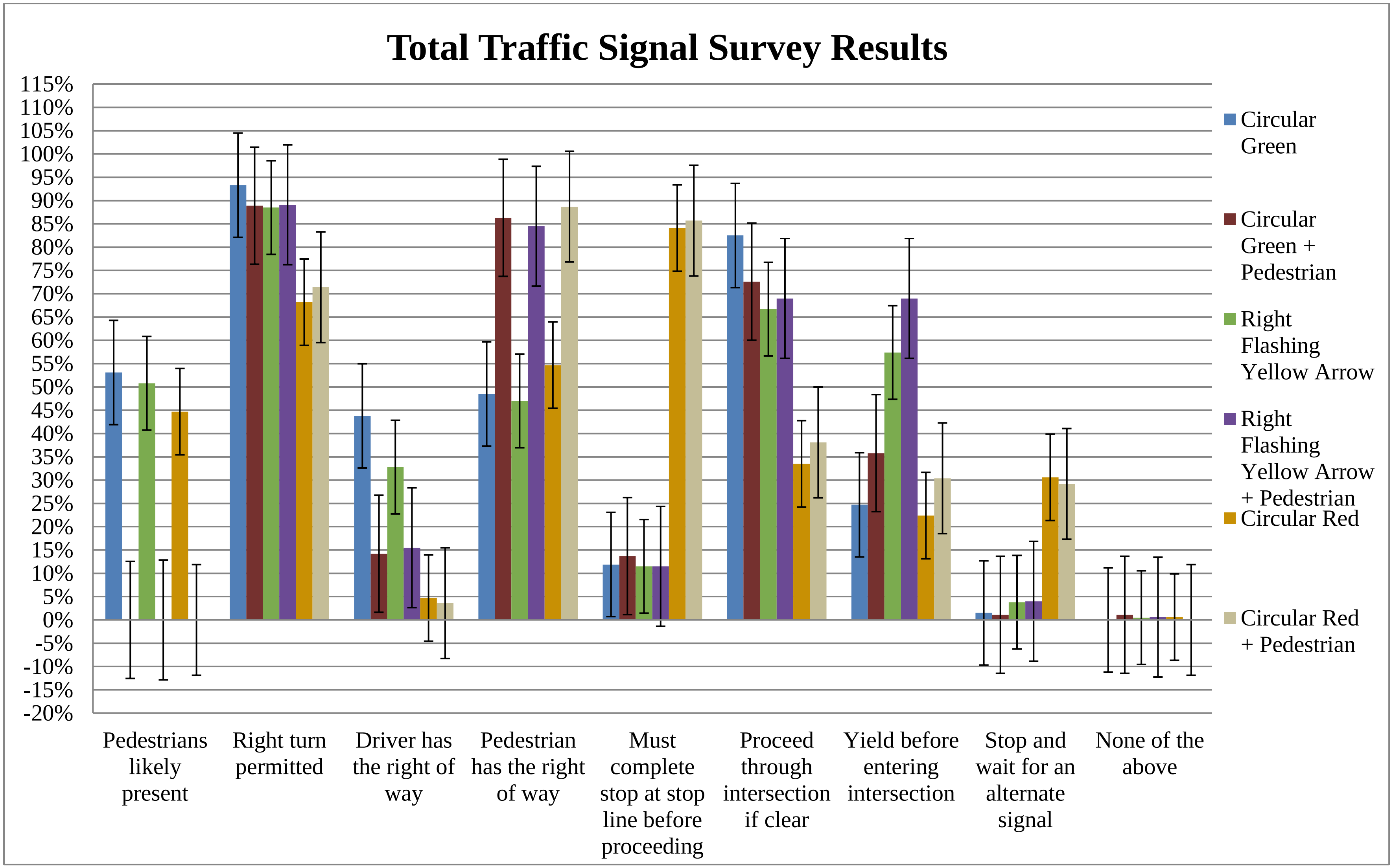

Figure 5: Survey Responses for All Traffic Signal Scenarios and Showing Error Bars

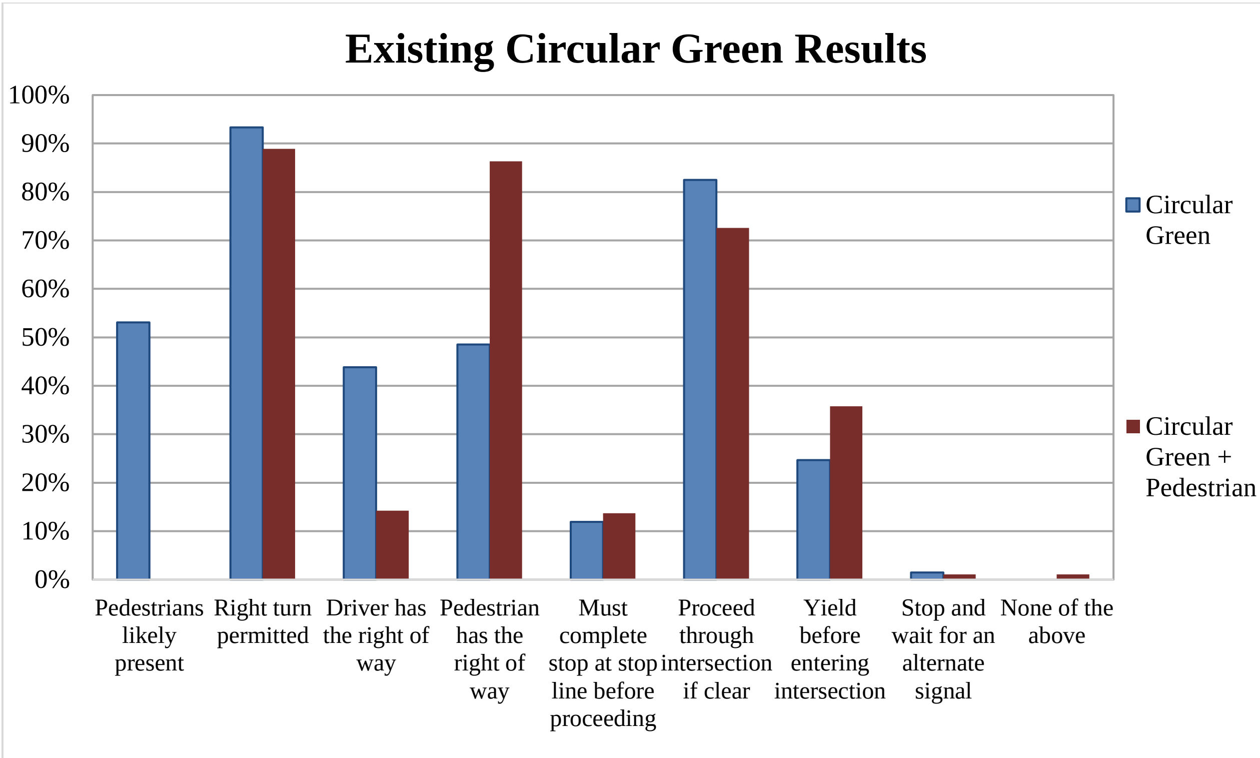

Figure 6: Survey Results for the Existing Circular Green Signal Scenario

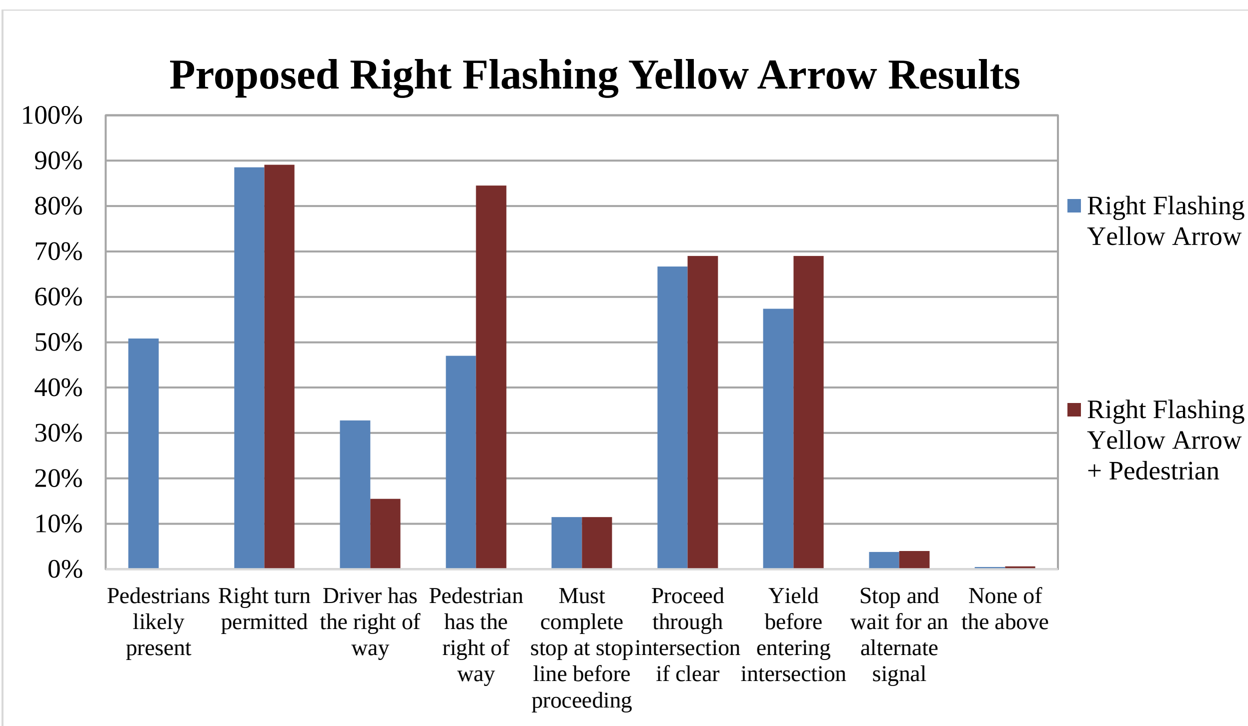

Figure 7: Survey Results for the Proposed Right Flashing Yellow Arrow Signal Scenarios

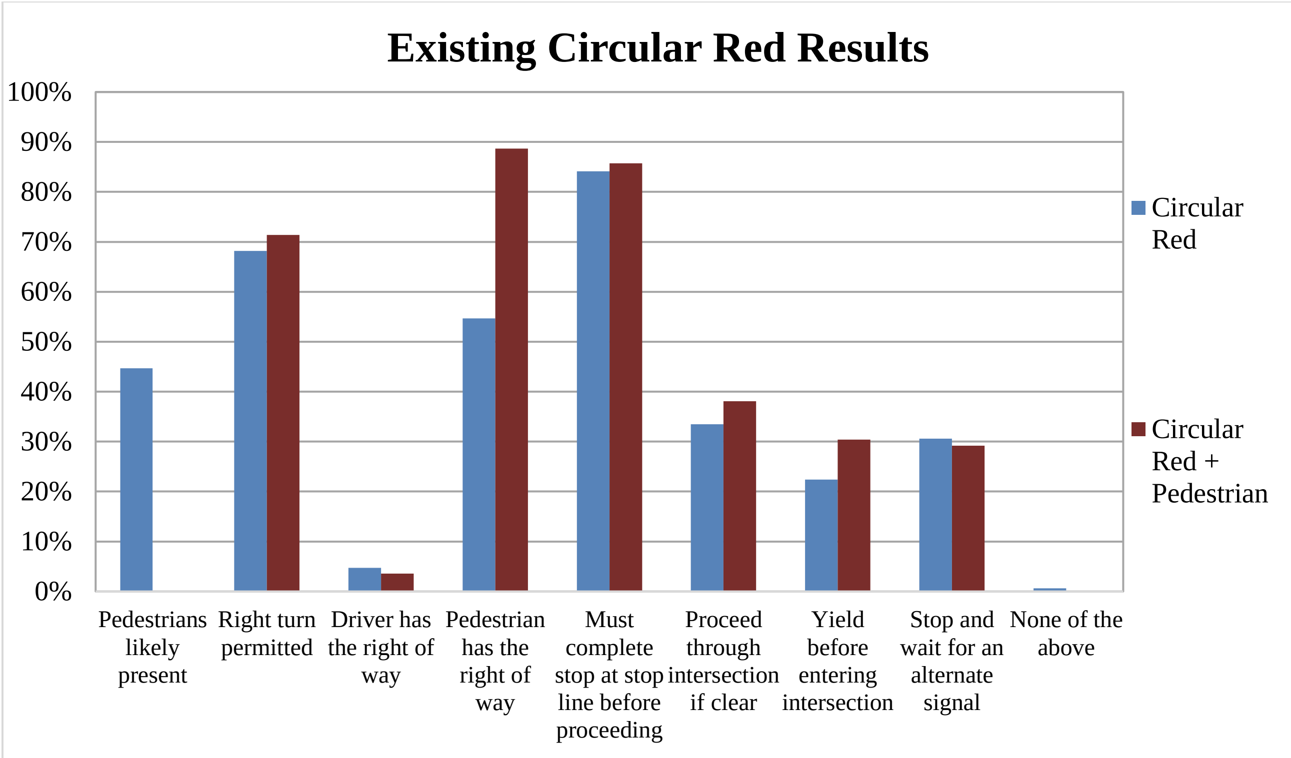

Figure 8: Survey Results for the Existing Circular Red Signal Scenarios

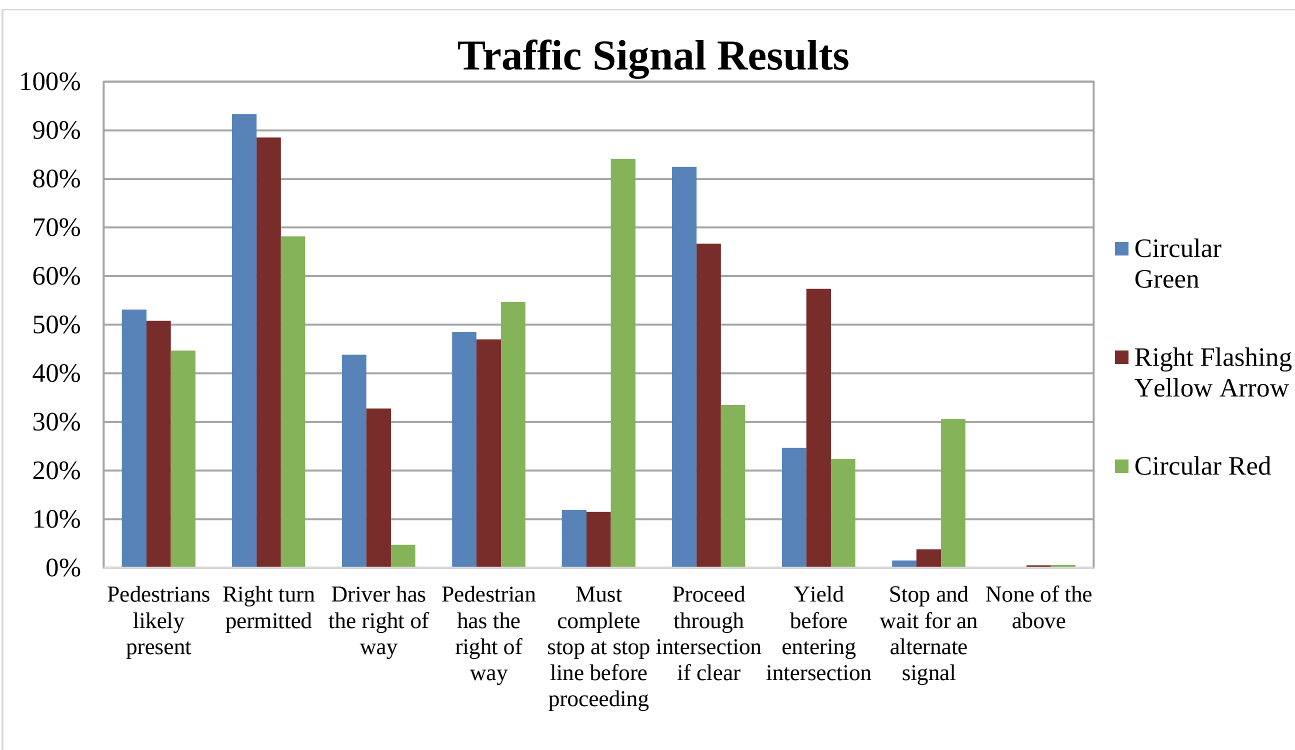

Figure 9: Survey Results Comparing the Observed Signal Scenarios

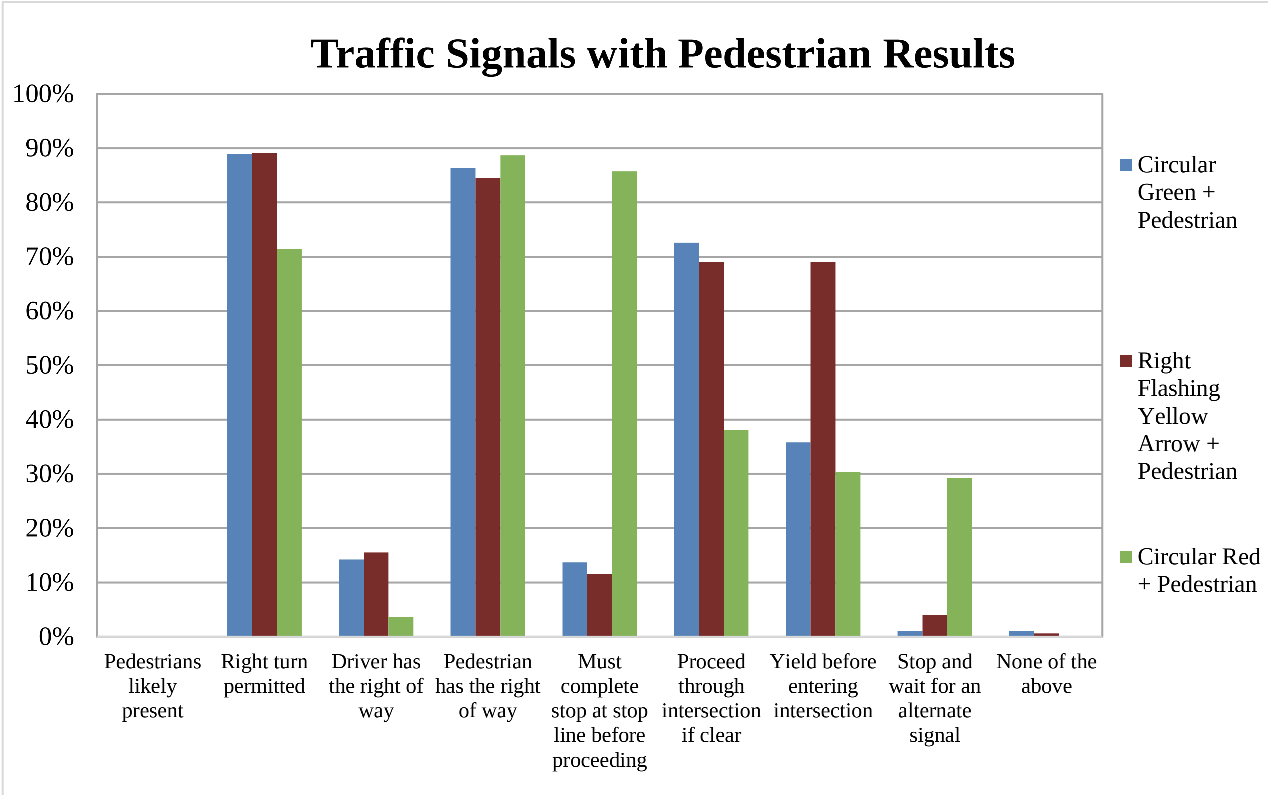

Figure 10: Survey Results Comparing Observed Signal Scenarios that Display Crossing Pedestrians

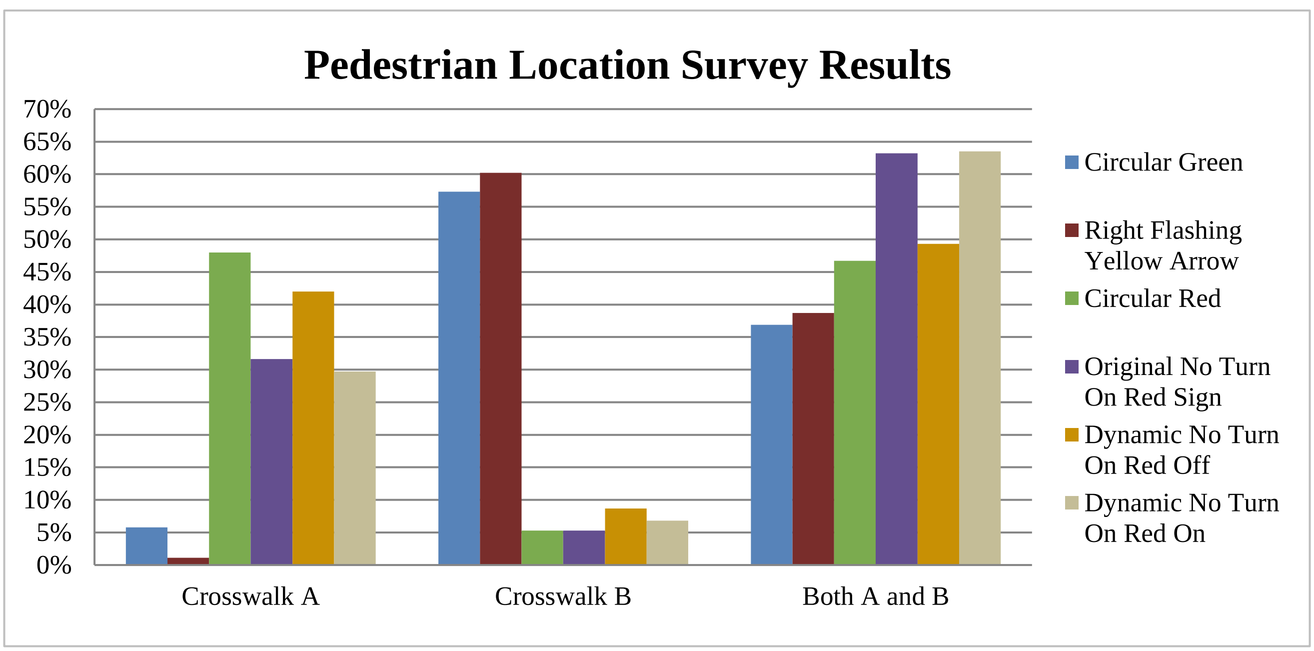

Figure 11: Survey Responses for Pedestrian Location Scenarios

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 listed in **Table 10** and shown in

Figure 12. 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 and with a heavy understanding the pedestrians would be crossing at crosswalk A as seen in and distinctly recognize both crosswalks could be utilized; i.e. during an all red phase.

Initially respondents were asked if a right turn was permitted 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 80.7% respondents identify that RTOR is permitted and while the sign is activated only 7% respond it is permitted. The response 'Must complete stop at stop line before proceeding' revealed 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 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 determined there was no statistical difference between the compared scenarios as seen in **Table 10**.

Table 10: 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

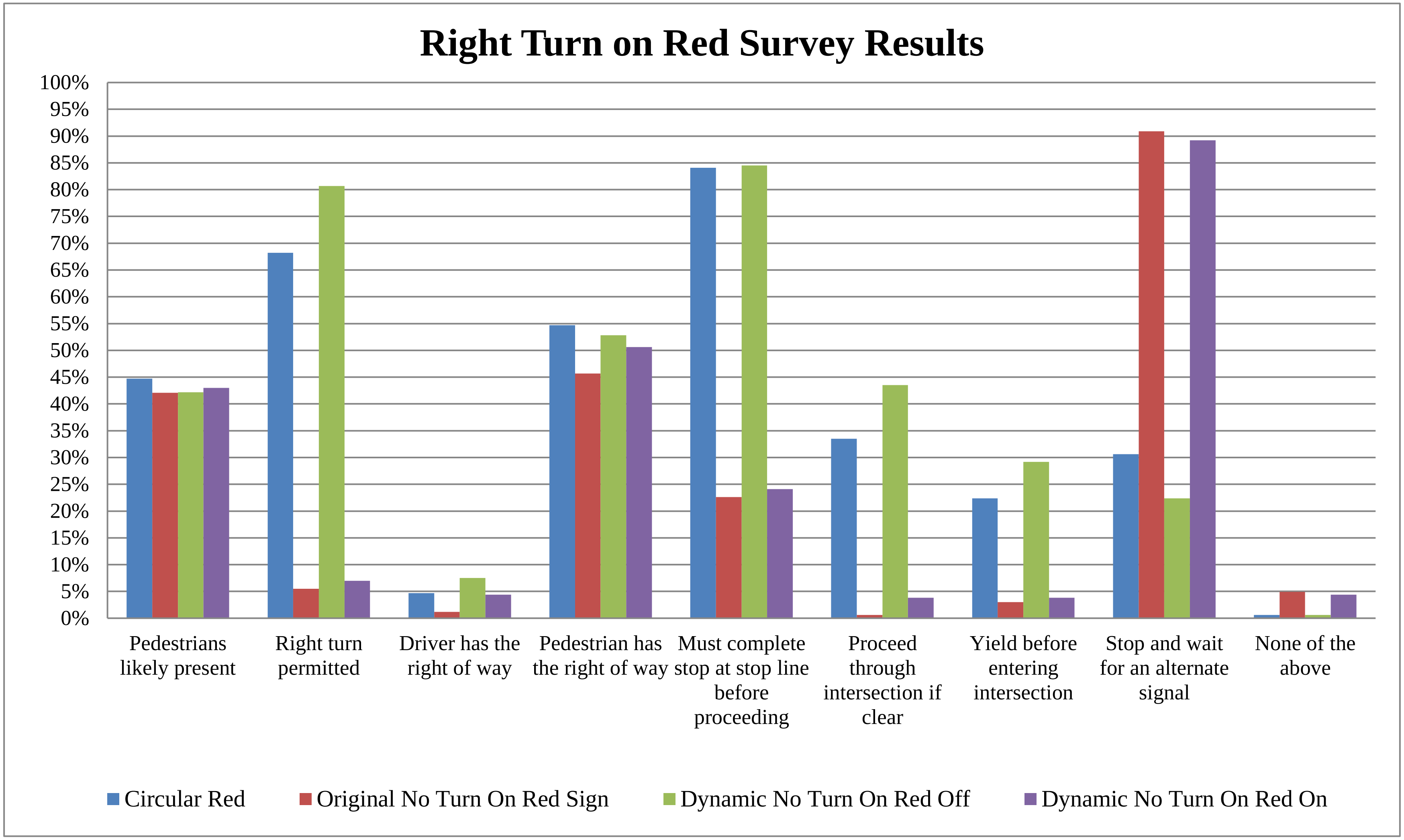

Figure 12: Survey Results for Right Turn on Red Device Scenarios

4.3 Microsimulation

Prior to any analysis could be done on the microsimulation created in VISSIM, the intersection had to be calibrated for accuracy. As previously mentioned, the calibration method in use came from the FHWA Traffic Analysis Toolbox as seen in **Table 6**. For the calibration target for Route 9 Eastbound direction link, due to field volumes exceeding 700 vehicles per hour, the simulated vehicle count must be within 15% for 85% of the runs performed. With an observed vehicle count found in the field to be 981, the simulated count must fall within 148 vehicles for 9 out of the 10 run that were done and that target was met. The other three legs of the intersection that consists of the Snell Street, Route 9 Westbound, and University Drive links; the criteria that must be met for these links having field volumes less than 700 vehicle per hour, the simulated volume count must be within 100 vehicles per hour of the observed field volume for 85% of the runs. For all 10 run, the change in volume between the simulated counts and the field counts did not exceed 100 vehicles per hour. The final criteria to be met for calibration is the volume for the sum of all links which must fall within 5% of the total observed field volume. The field volume for the hour observed consisted of 2312 vehicles and the simulated count must fall within 116 vehicles which were met for all 10 runs. **Table 11** breaks down the volumes for each link both simulated and observed and their respected change in volume, along with the entire intersection volumes. It can be seen that all criteria for calibration were met for the existing conditions allowing adjustments to be made to the intersection.

Table 11: VISSIM Microsimulation Volume Calibration

Run	Link	Simulated Vehicle Count	Observed Field Vehicle Count	Change in Volume	Run	Link	Simulate d Vehicle Count	Observed Field Vehicle Count	Change in Volume
1	Rt9EB	983	981	-2	**6**	Rt9EB	978	981	3
	Snell	171	205	34		Snell	197	205	8
	Rt9WB	573	565	-8		Rt9WB	570	565	-5
	Univ.	557	561	4		Univ.	592	561	-31
	Sum	2284	2312	-28		Sum	2337	2312	25
2	Rt9EB	952	981	29	**7**	Rt9EB	990	981	-9
	Snell	208	205	-3		Snell	204	205	1
	Rt9WB	543	565	22		Rt9WB	538	565	27
	Univ.	553	561	8		Univ.	577	561	-16
	Sum	2256	2312	-56		Sum	2309	2312	-3
3	Rt9EB	991	981	-10	**8**	Rt9EB	1002	981	-21
	Snell	218	205	-13		Snell	227	205	-22
	Rt9WB	575	565	-10		Rt9WB	538	565	27
	Univ.	557	561	4		Univ.	602	561	-41
	Sum	2341	2312	29		Sum	2369	2312	57
4	Rt9EB	956	981	25	**9**	Rt9EB	979	981	2
	Snell	197	205	8		Snell	231	205	-26
	Rt9WB	566	565	-1		Rt9WB	591	565	-26
	Univ.	538	561	23		Univ.	526	561	35
	Sum		2312			Sum	2327	2312	15
5	Rt9EB	1003	981	-22	**10**	Rt9EB	964	981	17
	Snell	194	205	11		Snell	191	205	14
	Rt9WB	576	565	-11		Rt9WB	594	565	-29
	Univ.	512	561	49		Univ.	612	561	-51
	Sum	2285	2312	-27		Sum	2361	2312	49

Index: Rt9EB (Route 9 Eastbound), Snell (Snell Street),
Rt9WB (Route 9 Westbound), Univ. (University Drive)

When adding the flashing yellow arrow to the right turning links, the simulation was run for visual analysis. In comparison to the base conditions, the model ran free flow and the new signal did not cause additional backup or vehicles to perform illegal maneuvers. Speed data was collected for ten runs for both the existing condition and the proposed flashing yellow arrow in three pedestrian classifications. The first run for both scenarios consisted of the observed number of pedestrians that was collected in the field, considered the base condition. The second increased the pedestrian count at each crosswalk by five, and the third increased the pedestrians by ten compared to the base condition. For each pedestrian consideration, the flashing yellow arrow scenario resulted in a lower average speed than the existing circular green over the ten runs, as seen in **Table 12**. As previously mentioned two models were created to represent the activated and deactivated no turn on red sign. The base condition that included the ability to make the right turn on red represented the deactivated scenario of the dynamic sign and removing the ability to make the right turn on red represented the activated sign. It was determined that this method would be feasible based on the survey data; that the proposed activated dynamic sign responses mirrored the current no turn on red condition responses and the deactivated sign responses mirrored the absence of a no turn on red sign responses. While running both simulation scenarios, there was no visual implication to allowing the right turn on red or not. From the data collected, there was little to no change in the number of vehicles making its way through the intersection as a result of prohibiting the right turn on red as seen in **Table 13**. The change in queue delay, over the entire observed hour, from allowing right turns on red and prohibiting right turns on red yielded no statistical difference causing minimal impact over the observed hour on the intersection across ten simulation runs, as seen in **Table 14**. Traffic continued to flow freely and the total input vehicle count successfully entered and exited the intersection within the observed hour.

Table 12: VISISM Speed Evaluation between Existing and Proposed Conditions

	Pedestrian Base Condition		5x Pedestrian Increase		10x Pedestrian Increase	
Simulation Run	**Existing** (avg. m/s)	**FYA** (avg. m/s)	**Existing** (avg. m/s)	**FYA** (avg. m/s)	**Existing** (avg. m/s)	**FYA** (avg. m/s)
1	16.2199	12.9226	11.5079	11.5055	10.2084	10.1840
2	18.5414	12.6364	11.3373	11.3401	10.1552	10.1350
3	17.2459	12.7052	12.1457	12.1422	10.6157	10.5917
4	17.4306	12.9116	11.8512	11.8483	10.6157	10.5960
5	18.6616	13.4588	12.3409	12.3415	11.0248	11.0777
6	18.2046	13.0679	11.8593	11.8585	10.8117	10.7947
7	19.0580	12.6713	11.0833	11.0425	10.4272	10.4096
8	17.6233	13.6150	12.0592	12.0554	10.2902	10.2746
9	16.9614	13.1222	11.9046	11.9049	10.7981	10.7799
10	17.0681	12.8320	11.7438	11.7408	10.5983	10.5858
T-Value	15.66		0.03		0.09	
P-Value	**<0.01***		0.49		0.46	

*p-value considered statistically significant

Table 13: Number of Vehicles Traversing Signalized Intersection

Run	Link	RTOR	NTOR	Difference	Run	Link	RTOR	NTOR	Difference
1	Rt9EB	982	982	0	**6**	Rt9EB	974	974	0
	Snell	171	171	0		Snell	197	197	0
	Rt9WB	562	562	0		Rt9WB	564	564	0
	Univ.	556	556	0		Univ.	592	592	0
2	Rt9EB	948	948	0	**7**	Rt9EB	986	986	0
	Snell	214	214	0		Snell	206	206	0
	Rt9WB	535	535	0		Rt9WB	531	530	1
	Univ.	553	553	0		Univ.	576	576	0
3	Rt9EB	984	984	0	**8**	Rt9EB	992	992	0
	Snell	221	221	0		Snell	229	229	0
	Rt9WB	564	564	0		Rt9WB	532	532	0
	Univ.	557	557	0		Univ.	601	601	0
4	Rt9EB	951	950	1	**9**	Rt9EB	975	975	0
	Snell	197	197	0		Snell	233	233	0
	Rt9WB	560	561	-1		Rt9WB	589	589	0
	Univ.	536	536	0		Univ.	526	526	0
5	Rt9EB	999	999	0	**10**	Rt9EB	961	961	0
	Snell	195	195	0		Snell	191	191	0
	Rt9WB	566	566	0		Rt9WB	587	587	0
	Univ.	511	511	0		Univ.	611	611	0

Table 14: Right Turn on Red vs. No Turn on Red Difference in Total Queue Delay in Seconds per Total Observed Hour

Queue Delay (s)			
Run	**RTOR**	**NTOR**	**Difference**
1	129.34	107.58	*21.75*
2	141.54	111.06	*30.47*
3	122.61	120.70	*1.91*
4	122.44	129.14	*-6.70*
5	141.37	142.45	*-1.08*
6	126.72	136.64	*-9.92*
7	133.41	136.54	*-3.13*
8	129.47	143.84	*-14.37*
9	149.95	131.86	*18.08*
10	133.31	132.29	*1.02*
	T-Value		*0.788*
	P-Value		*0.220*

Due to limitations in the SSAM software, limited analysis was able to be done determining the variation in conflicts between signal conditions. Based on the overall number of conflicts collected by SSAM for both the current condition represented in VISSIM and the proposed flashing yellow arrow, there was a decrease in conflicts in the proposed scenario. In comparing the activated and deactivated dynamic no turn on red scenarios, the overall number of conflicts detected by SSAM decreased when the right turn on red was prohibited. The total number of conflicts being compared can be seen in **Table 15**.

Table 15: SSAM Conflict Comparison between Existing and Proposed Conditions on Right Turning Links Over Ten Simulation Runs

	Existing	**FYA**	**Difference**
Conflicts	29	22	7
	RTOR	**No RTOR**	**Difference**
Conflicts*	1022	1017	3

*includes approaching lane links

CHAPTER 5
DISCUSSION

5.1 Crash Data

The study of crash data bests paints the picture of conditions that need to be observed to further implement change to increase safety of all users and lower potential injury and conflict. There are over 1,300 drivers a year that are involved in an accident as a result of making a right turn at a signalized intersection where over 200 of those people leave the scene injured. Investigation of evidence of contributing factors to these crashes can set a framework of which interactions need the consideration of new traffic control devices. All right turn crashes at a signalized intersection can be seen on the map in **Figure 13**.

The fact that in a four year window the yearly collisions by category and injury rate remain rather consistent; there is concern for a relative cause. With 76.1% of the collisions are with another moving vehicle as well 215 pedestrians and 248 cyclists were hit alerts transportation engineers of a possible disconnect at the intersection. Due to a low number of crashes in comparison to the total crash rate, the first assumption would consider weather and surrounding conditions to be at fault.

Based on the data, 70.17% of the crashes occur on a clear day. While clear dry days are the majority of the time roadway users are active, this could rule out limited sight or slippery conditions as a result snow, rain, etc. and leading causes for these types of crashes. Removing snow, rain, sleet, etc. from the picture the concurrent weather deposits accumulating on the roadway surface can be assumed not contributing and also confirmed as the data results conclude 77.3% of the accidents take place on a dry roadway surface and 72.41% of crashes happen during the daytime, ruling out limited visibility due to darkness. While the crashes during clear conditions are sporadically throughout the state and near larger cities, an assumption can be made that the extent of a problem is made at the driver level.

This crash evaluation rejects environmental and atmospheric conditions as a contributor to the right turn crashes at signalized intersection; therefore leading researchers to believe there may be a miscommunication between roadway users. This reiterates that the leading contributions to crashes at signalized intersections are due to driver error including inattention, illegal maneuver, or other users' false assumption based on NHTSA's research (*3*). Noticing a trend of reoccurring locations, as seen in **Figure 14,** provides target areas for future studies at a local level. Large clusters have formed around cities including Boston, Springfield, and Worcester which due to high populations could be expected but the consistency in the other locations yields curiosity. The cluster locations are visually noticeable throughout the state and remain a problem area over the four years being observed resulting in a pool of locations to be further studied at a local level.

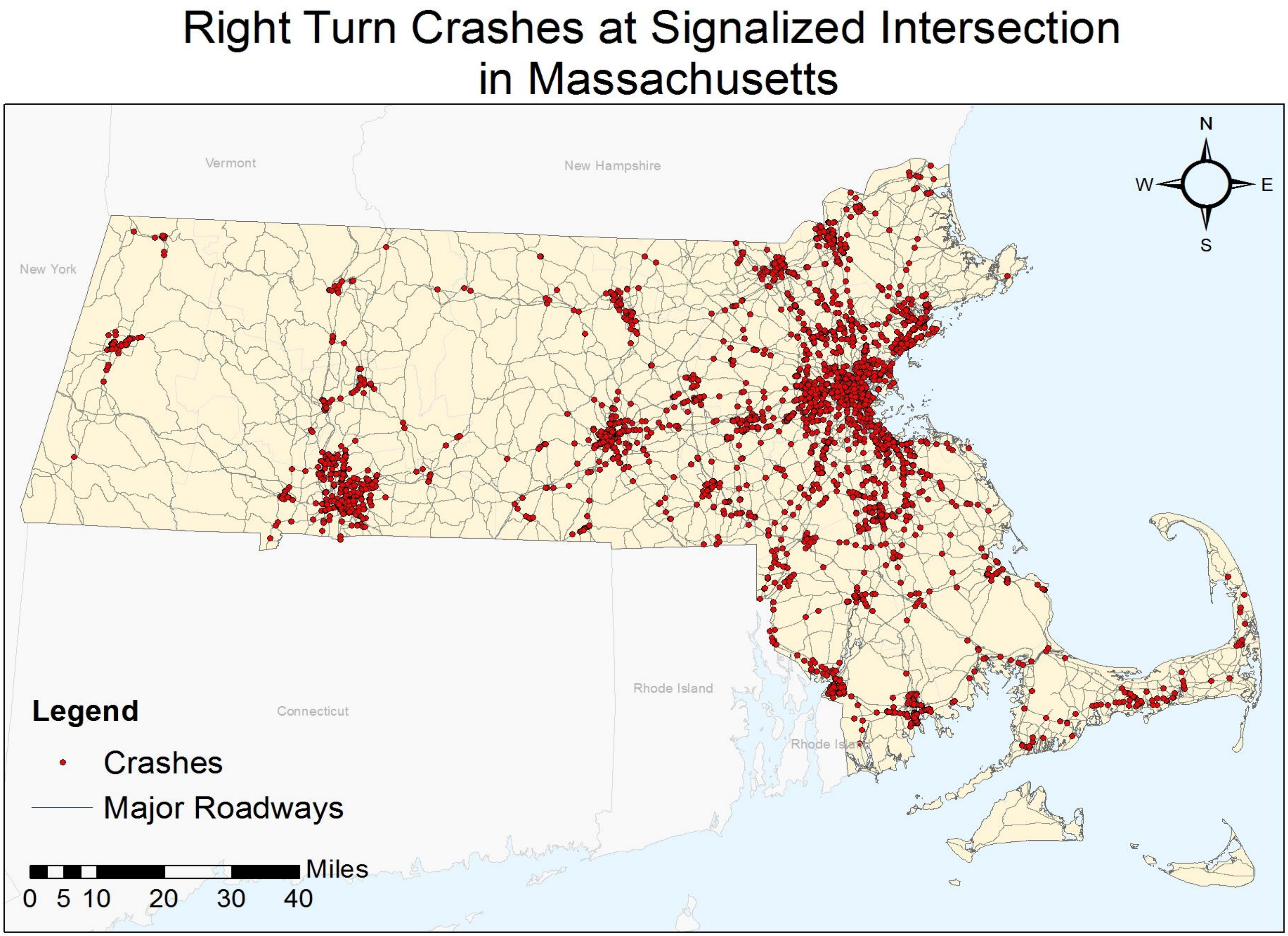

Figure 13: Right Turn Crashes at Signalized Intersections in the Massachusetts in the Years 2011-2014

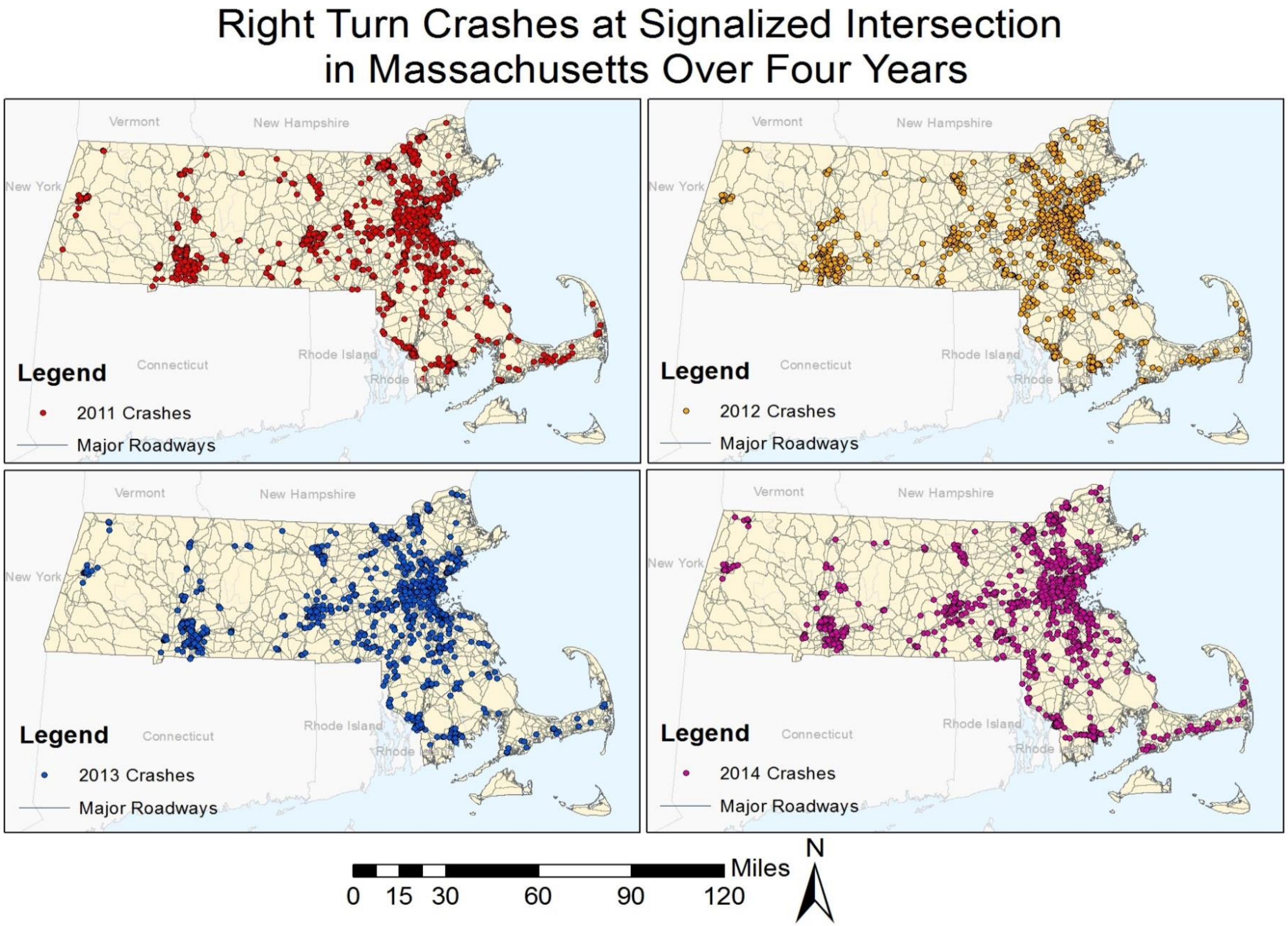

Figure 14: The Comparison of Right Turn Crashes at Signalized Intersections in Massachusetts Over Four Years

5.2 Survey

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 understanding of permissive right turns, the existing circular green indication scenario was compared to the proposed signal condition containing a flashing yellow arrow for right turn applications. The existing condition set a baseline for driver comprehension as they think through the action of making a right turn in two scenarios, with and without a pedestrian crossing. The options provide 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 options response 'Must complete stop at stop line before proceeding' and 'Stop and wait for alternate signal' proves 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 to the flashing yellow arrow signal.

Majority of survey respondents have acknowledged the possibility of pedestrians crossing at signalized intersections. When further asked at what location they would be crossing, parallel to the permissive phase as permitted yet still notice that traffic dependent pedestrians may also cross perpendicular to the green phase. This understanding of pedestrian location provides indication of driver vigilance to other roadway users increasing attention more towards pedestrian rather than solely vehicles.

The existing conditions during the red phase consist of a circular red ball signal and a circular red ball signal with the R10-11 “No Turn on Red” sign. Based on survey results drivers understanding of if a right turn is permitted was recognized. The majority of respondents acknowledged the right turn is permitted when just a circular red was displayed while only five percent of responses believed one can turn with a 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 majority of 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 responses were placed observing a 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 the driver comprehension across both scenarios to stop before entering the intersection. It can be concluded that there is significant similarities in the understanding of the signs’ intended message.

5.3 Microsimulation

The overall creation of the various simulated scenarios yielded in successful free flowing intersection. Based on visual analysis it can be seen that the addition to the proposed devices in this research were not detrimental to the intersection in question. As a result of this it can be determined that the flashing yellow arrow for the right turn application and the dynamic no turn on red sign can successfully be implemented into a signalized intersection contingent on driver compliance and understanding, which was deemed feasible for the simulation. While the exact devices that are in question for this research are not precisely provided through the VISSIM software, comparable applications were executed to achieve a similar outcome. With further investigation and validation of the implementation of the proposed devices in VISSIM, the compliance rates could be adjusted based on the survey results to represent the most accurate model.

With the model created and the only adjustment made to the field condition being the addition of the flashing yellow arrows, the average speed collected over ten runs decreases with the presence of the flashing yellow arrow. This same trend occurs when there is an influx of pedestrians added to the intersection. The base condition where the number of pedestrians observed was consistent with collected field data yielded a statistically significant decrease in speed with the addition of the flashing yellow arrow as seen in **Table 12**. The decrease in speed is attributed to what is believed to be the increase in yielding of vehicles before making a right turn during their respected green phase, which supports the hypothesis that the flashing yellow arrow increases the yielding compliance of right turning vehicles. As the amount of pedestrians increased, the gap in speed difference between the existing circular green and proposed flashing yellow arrow decreased. This small difference can be attested to such a large amount of pedestrians that all vehicles are yielding due to the presence of a pedestrian rather than solely a reaction to the flashing yellow arrow signal. The slight decrease in speed does present a consistent pattern across the current and proposed conditions.

The use of SSAM was intended to assess the change in conflicts between the current conditions and the proposed devices being researched. As a result of limitations in the SSAM software, the full analysis that was envisioned could not be performed. With the thresholds set to TTC at 2.7 and PET at 8, the base condition with just the circular green resulted in a total of 1,729 conflicts and 29 on right turning links while the flashing yellow arrow resulted in 1,650 total conflicts and 22 conflicts on right turning links. This supports the hypothesis that the flashing yellow arrow will increase yielding to overall limit potential conflict with crossing pedestrians. The right turn on red permitted scenario yielded 1,022 conflicts on right turning and their approaching links while prohibited right turns on red yielded 1,017 conflicts on right turning and their approaching links. This also supports the hypothesis that the dynamic no turn on red sign prevents vehicles from conflicting with pedestrians by prohibiting vehicles to encroach on the crosswalk and interfere with pedestrian travels by activating the no turn on red sign. It can be noted that these overall conflict counts are relatively high due to the adjustment in the thresholds to attempt to account for pedestrian behavior. Due to a glitch in the software, the mapping function of SSAM is unavailable therefore the exact locations of these conflicts cannot be determined past just the link they occur on. Crosswalk links are not determined in SSAM therefore the mapping function is vital to decipher if the conflict occurs where the crosswalk was created or occurred at another location on the link that intersects the crosswalk. While it is possible to filter the right turning links, without the pedestrian designation and mapping location a pedestrian-vehicle conflict cannot be accurately determine. As development continues to adapt the software for better detection of pedestrians based on speed and vehicle size, which have been observed but not validated to be less than 5mph and 0.3-0.5m, respectively the lack of the mapping function prohibits confirming if the determined conflicts occurred with pedestrians. Overall, we can see a decrease in conflicts when the flashing yellow arrow is present and there is the ability to deactivate the right turn on red.

CHAPTER 6
CONCLUSION

Significant efforts have been made to effectively and safely communicate permissive turns due to the variety of vehicular turning movements at signalized intersections. The objective of this research was to evaluate the driver comprehension and behavior while completing a right turn maneuver at a signalized intersection. While aiming to improve the safety between vehicles and pedestrians, the flashing yellow arrow for right turn applications and dynamic no turn on red were evaluated to determine whether drivers grasp the message of the devices. Various methods including a static survey, analyzing crash data, and reviewing microsimulation were used in this research.

The survey portion was performed 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 flashing yellow arrow, and dynamic no turn on red sign. The results indicate that drivers have a strong comprehension of the flashing yellow arrow 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 flashing yellow arrow supporting the hypothesis that drivers yielding compliance would increase. The data reveals the majority of drivers perceive pedestrians to cross parallel to the green signal while the flashing yellow arrow scenarios increase the assignment of pedestrians to crosswalk B. Considering the signal scenario options the general concept of the flashing yellow arrow 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 shows great similarities with no statistical difference, supporting the hypothesis that there will be a strong understanding of the sign. The majority of the responses depicted 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. With a about 90% of respondents understanding to wait for an alternate signal to make a turn when the R10-11 and activated no turn on red are present, this supports the hypothesis that pedestrian conflicts would decrease as vehicles would not encroach on the crosswalk since the turn in now restricted and that message is understood by drivers.

A crash analysis provides locational and environmental understanding of factors leading to right turn crashes at signalized intersections. Conditional analysis was performed on 5,854 right turn crashes at signalized intersections between the years of 2011 to 2014. With a yearly average of 17.83% injuries resulting from a crash, and over 100 exposed users including pedestrians and cyclists hit per year, the constant threat of harm brings light to the fact that there must be a reason contributing to the crashes from the right turn maneuver. Over 70% of the observed crashes occurred during the day with clear weather and a dry roadway which provides evidence to support that human factors' could be the driving force behind these crashes. While studies have demonstrated drivers making a right turn have 'inattentional blindness' while solely focusing on one of the many conflicting maneuver (*9*), as well as establishing a scanning pattern due to selective attention to look for the most threatening conflict while neglecting the additional conflicts (*10*), the miss connection between users increase the potential for a collision. The use of crash mapping generated visible clusters where large numbers of crashes have occurred. Observation of crashes over time provides target locations where high volumes of crashes consistently occur. Based on determining reoccurring crash clusters, further investigation on a local level would be the next step in future research.

A calibrated microsimulation was created that constructed a signalized intersection located in Amherst, Massachusetts. This simulation was recreated to represent the field conditions, the flashing yellow arrow condition and prohibiting a right turn on red condition where each proposed device condition kept all factors consistent with the slight change of solely the device in question. For each model run the intersection run in free flow with no visual confusion or vehicle error. Over ten runs, speed data was collected for the base condition and flashing yellow arrow models. The average harmonic speed for the flashing yellow arrow scenario was determined to be statistically significantly lower than the existing condition scenario. The lower speeds is connected to the increase in yielding or slowing down before making the right turn in the presence of the flashing yellow arrow present which further supports the suggestion of drivers increasing driver yielding compliance. With limited usability of SSAM to analyze pedestrian conflicts, the overall conflict count was used to compare existing and proposed conditions. There was a decrease in overall conflicts from the existing condition to the flashing yellow arrow conditions and a decrease in conflicts from right turn on red permitted to right turn on red prohibited.

6.1 Limitations

The largest limitation in this research is the access to the SSAM program. This program has not be verified for determining pedestrian conflict; while research has been done to determine trends to identify pedestrians the software currently does not have a pedestrian definition. As well, due to software glitches the mapping function was not accessible which prevented using location as a method to determine possible conflicts with pedestrians.

6.2 Future Work

As a result of the SSAM limitations, future work in determining intersection conflicts with pedestrians can be done when a new version of the software is release and the map function is operational. While FHWA is in the works of including pedestrian composition when detecting conflicts when this is further evaluated it can be utilized to continue flashing yellow arrows and dynamic no turn on red analysis.

After determining driver comprehension of the devices in question for this research through static evaluation and microsimulation, a driving simulator experiment would be beneficial to test this understanding behind the wheel. A driving simulator study would safely allow for the evaluation of driver understanding and comprehension while in a more realistic driving environment to determine driver’s reaction and responses to the devices.

APPENDIX:
CRASH DATA EXTRACTION STRUCTURED QUERY LANGUAGE

SQL input into the Safety Data Warehouse to extract Massachusetts crash data:

```
select distinct
c.CRASH_NUMB,
c.CRASH_DATE,
c.CRASH_TIME,
s.INJY_STAT_DESCR,
c.RDWY_JNCT_TYPE_CODE,
c.TRAFY_DESCR_CODE,
c.TRAF_CNTRL_DEVC_TYPE_CODE,
c.FIRST_HRMF_EVENT_CODE,
c.FIRST_HRMF_EVENT_LOC_CODE,
c.MANR_COLL_CODE,
c.WEATH_COND_CODE_1,
c.WEATH_COND_CODE_2,
c.AMBNT_LIGHT_CODE,
c.ROAD_SURF_COND_CODE,
c.SPEED_LIMIT,
--d.DRVR_CNTRB_CIRC_CODE_1,
--d.DRVR_CNTRB_CIRC_CODE_2,
c.CRASH_SEVERITY_CODE,
v.VEHC_UNIT_NUMB,
v.VEHC_MANR_ACT_CODE,

CASE
When     c.CRASH_SEVERITY_CODE in (2, 3) then 'Injury'
When     s.INJY_STAT_CODE in (2, 3, 4, 1) then 'Injury'
When c.CRASH_SEVERITY_CODE = 1 then 'PDO'
when s.INJY_STAT_CODE = 5 then 'PDO'
else 'Unknown' End As "injury"

from
cds.CRASH c,
        (select
             c.CRASH_NUMB as "crash_numb",
             min(p.INJY_STAT_CODE) as "injy"
         from
            cds.CRASH c,
            cds.person p
         where
            c.CRASH_NUMB = p.CRASH_NUMB and

            to_char(c.CRASH_DATE, 'YYYY') in ('2011','2012','2013','2014')
        group by
            c.CRASH_NUMB
```

```
    ) "inj",
  cds.INJURY_STATUS s,
  cds.DRIVER d,
  cds.VEHICLE v

where
c.RDWY_JNCT_TYPE_CODE in (2,3) and
d.CRASH_NUMB = c.CRASH_NUMB and
v.CRASH_NUMB = c.CRASH_NUMB and
c.CRASH_NUMB = "inj"."crash_numb" and
  "inj"."injy" = s.INJY_STAT_CODE and

      to_char(c.CRASH_DATE, 'YYYY') in ('2011','2012','2013','2014')
```

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