Analyzing Speed Choice Near Pedestrian Crossing Treatments

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Abstract

Pedestrian crossing treatments, such as Pedestrian Hybrid Beacons (PHBs) and Rectangular Rapid-Flashing Beacons (RRFBs), are traffic control devices implemented to help pedestrians safely cross busy or higher-speed roadways at midblock crossings and uncontrolled intersections. This study aims to assess the effectiveness of the PHB and RRFB by analyzing drivers' speeding behavior under different roadway types with real-life traffic conditions. In order to understand the effect of pedestrian crossing treatments (i.e., PHB and RRFB) have on drivers' speeding behavior, this paper analyzes four zones (i.e., one upstream zone and three consecutive downstream zones. The proposed analysis framework was validated by the means of an empirical driving simulator study, based on two urban roads in the Central Florida region, North Alafaya Trail (SR-434) and South Orange Blossom Trail (US-441). The results revealed that the proposed modeling framework reflects drivers' difference in speed for the different pedestrian crossing treatments. The results suggest that with proper understanding of the PHB, the PHB can reduce drivers speed even beyond the location of the PHB. Meanwhile, the RRFB does have some effect in speed reduction beyond the location of the RRFB, however many drivers failed to acknowledge the RRFB. It is suggested that when drivers' have proper education on the use of the PHB to reduce speed safely and for the installation of RRFB be on roads with two or less lanes and a speed limit less than 40 mph. While the main purpose of the pedestrian crossing treatments is to help pedestrians cross safely, speed reduction can be considered a byproduct as revealed in this study.

Keywords: Speed Reduction; Pedestrian crossing treatments; Pedestrian Hybrid Beacon; Rectangular Rapid-Flashing Beacons; Driving Simu

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1. Introduction

According to the National Highway Traffic Safety Administration (NHTSA), nearly 26% (9,478) of all traffic fatalities in 2019 were related to speeding. Speeding is a type of aggressive driving behavior that has several contributing factors like, traffic, tardiness, and inattention. Speeding can create hazards for passengers, other drivers, and nearby vulnerable road users. Some of the reasons as to why speeding is dangerous is because of the increased stopping distance, greater potential for a loss of control and steering, and a higher degree of crash severity if a crash does occur. Besides the hazards that speeding causes, speeding can also limit the effectiveness of various traffic safety programs that are implemented to reduce the other traffic safety risks and pedestrian safety initiatives.

1.1. Rectangular Rapid-Flashing Beacon

Rectangular rapid-flashing beacons (RRFBs) are pedestrian-actuated conspicuity enhancements used in combination with a pedestrian, school, or trail crossing warning sign to improve safety at uncontrolled, marked crosswalks [1]. Shurbutt et al. examined the effectiveness of RRFBs in Florida, Illinois, and Washington, D.C. [2]. In their study, they observed that the yielding behavior increased from an average of 2% to 86% at the Florida RRFB sites and was 85% at the 2-year follow-up. The results of this analysis confirmed a highly significant level change following the introduction of the RRFB that showed no sign of decay over time. Similar results were obtained at the District of Columbia and Chicago suburb sites. Hunter et al. also found similar results at a RRFB in Saint Petersburg, Florida, where the drivers' yielding increased from 2% to 54% after the introduction of the RRFB [3]. Dougald analyzed the effect of RRFB drivers' yielding with pedestrians and bicyclists in Virginia [4]. Dougald found that there was an increase from 32% to 61% after the RRFB was implemented. However, Fitzpatrick et al. observed that there was a lower rate of compliance for longer crossing widths and indicated that for a certain crossing distance width, a device other than the RRFB should be considered [5].

1.2. Pedestrian Hybrid Beacon

Pedestrian Hybrid Beacons (PHBs) can warn and control traffic at unsignalized locations and assist pedestrians in crossing a street or highway at a marked crosswalk [6]. Michigan Department of Transportation evaluated the safety effectiveness and driver yielding rates for pedestrian crossing treatments, including ten PHB locations and eight RRFB locations in Michigan [7]. The study observed an average driver yielding rates of 75% at RRFB and 76% at PHB locations. The study concluded that their yielding rates was less than that found in other FHWA studies because of poor levels of driver and pedestrian understanding of how to respond to the devices. Fitzpatrick et al. studied the driver yielding rates at 22 RRFB locations and 32 PHB locations in Texas [5]. The study found driver yielding rates for RRFBs and PHBs as 86%, and 89%, respectively. Furthermore, the study mentioned that with more experience of a particular device (PHB or RRFB) one can expect an increase in driver yielding rates as the drivers became familiar with these devices. Fitzpatrick et al. also found that for wider crossing distances (i.e. higher number of lanes), PHB yielded better driver yielding rates than RRFB [8].

1.3. Objective of this study

In this study, a comparative driving behavior assessment method is proposed to analyze the effects of pedestrian crossing treatments (RRFB and PHB) on drivers' speeding behavior. Afterwards, an empirical experiment study with a driving simulator is conducted, which supports the proposed modeling framework.

2. Modeling Framework

The objective of this study is to analyze drivers' speeding behavior to pedestrian crossing treatments within different crossing treatments (RRFB and PHB) and road types. This section introduces a comparative assessment concept to capture drivers' decision making and speed adjustment process upstream and downstream of the pedestrian crossing treatments. It is expected that drivers adjust their speed based on when the pedestrian crossing treatment is activated. After the pedestrian treatment has been activated, drivers should make the decision to proceed or yield for the pedestrian before continuing their route. The disruption of traffic flow by the pedestrian treatment would cause the driver to gradually increase their speed after crossing the pedestrian treatment. Hence, the downstream was classified into three consecutive downstream segments of 100 ft. The speed adjustments could be categorized into 2 groups (i.e., the speed adjustment for the RRFB and the speed adjustment for the PHB). Specifically, the analysis of drivers' speed adjustment is to understand how drivers' respond to the pedestrian treatments and the effects that the pedestrian crossing treatments have on the drivers.

2.1. Analysis of variance (ANOVA)

Repeated measures Analysis of Variance (ANOVA) is the equivalent of the one-way ANOVA, but for related, not independent groups, and is the extension of the dependent t-test. A repeated measures ANOVA is also referred to as a within-subjects ANOVA or ANOVA for correlated samples. All these names imply the nature of the repeated measures ANOVA, that of a test to detect any overall differences between related means. A repeated measures ANOVA calculates an F-statistic, as

$$Repeated\ Measures\ ANOVA: \quad F = \frac{MS_{conditions}}{MS_{error}} \tag{1}$$

The ANOVA tests were conducted estimate the mean, 85th, and maximum speed for upstream and the downstream segment. It's important to note that there were not any significant differences in speed for segments beyond 100 ft downstream of the pedestrian crossing countermeasures. A detailed analysis for the segments of each roadway will be explained below.

3. Experimental Design

Once the comparative concept to characterize the drivers' adjustments with the pedestrian crossing treatments is proposed, an experimental study is required to support the proposed framework. A variety of circumstances including pedestrian crossing treatment type, traffic conditions, and road types are of interest. Hence, a driving simulator would be able to provide the necessary controls to explore all possible scenarios and should be an appropriate and cost-effective alternative compared with field tests. The driving simulator can give drivers the impression that they are driving a vehicle in the real word by simulating the real driving environment. By simulating vehicle motion according to drivers' operations, the vehicle kinematic data can be generated and used to analyze drivers' decisions.

The experiment was a within-subjects experiment. The scenario type (e.g., without/with pedestrian crossing treatments) were within variables, and each participant driver experienced randomly a scenario under both conditions of with a pedestrian crossing treatment (RRFB and PHB) and a base condition. The scenarios were modeled after two roads in the Central Florida region. Also, the participants drove both directions (Northbound and Southbound) for each of the scenarios. Hence, each participant was tested for 12 (2*2*3) scenarios. The advantage of a within-subjects experiment is that it controls extraneous participant variables and makes it easier to detect the relationships between the independent and dependent variables [9]

To prevent a participant from predicting the scenario type, multiple base scenarios were arranged between the pedestrian crossing treatments. In addition, to account for the carryover effect, the order of all scenarios that a participant driver experienced were based on Latin Square design [10-13].

3.1. Apparatus

The Smart and Safe Team (SST) driving simulator developed at the University of Central Florida (UCF) located in Orlando, FL was used to conduct the experiment and collect the data. The simulator has three screens (20.5 in. high and 27.9 in. wide) with a 135 degrees front field of view and left, middle, and right rear-view mirror. Participants interacted with the simulator by a control interface with steering wheel, pedals, and speedometer. All data were collected at 60 HZ.

3.2. Scenario Design

The experimental road in this study was based on two sections of urban roads in the Central Florida region, North Alafaya Trail (SR-434) and South Orange Blossom Trail (US-441). North Alafaya Trail is a is a six-lane arterial with 45 mph speed limit, while South Orange Blossom Trail is a six-lane arterial with a 40 mph speed limit. The selected sections are sections that have a high number of pedestrian activities. The segment of North Alafaya Trail may benefit with the installation of a pedestrian crossing treatment, while the of segment of South Orange Blossom Trail has three PHBs that were installed in October 2018. The section of North Alafaya Trail starts from the intersection of North Alafaya Trail and Science Drive and ends at the intersection of North Alafaya Trail and McCulloch Road. For the North Alafaya Trail section, the total length was about a 2-mile consisting of four zones: (1) upstream section and (2-4) downstream sections (100 ft each). The section of South Orange Blossom Trail starts from the intersection of South Orange Blossom Trail and Holden Avenue and ends at the intersection of South Orange Blossom Trail and 35th Street. For the South Orange Blossom Trail section, the total length was about a 0.88 mile consisting of four zones for each of the three pedestrian treatments: (1) upstream section and (2-4) downstream sections (100 ft each). The length of upstream segment was determined to ensure the driver was able to see the pedestrian treatment clearly from the start of the segment to the stop bar. The length of downstream segments was determined to ensure sufficient distance to understand the effects of the pedestrian crossing treatments. The pedestrian crossing treatment scenarios with the respected upstream and downstream sections for the Northbound scenarios are shown in Figure 1.

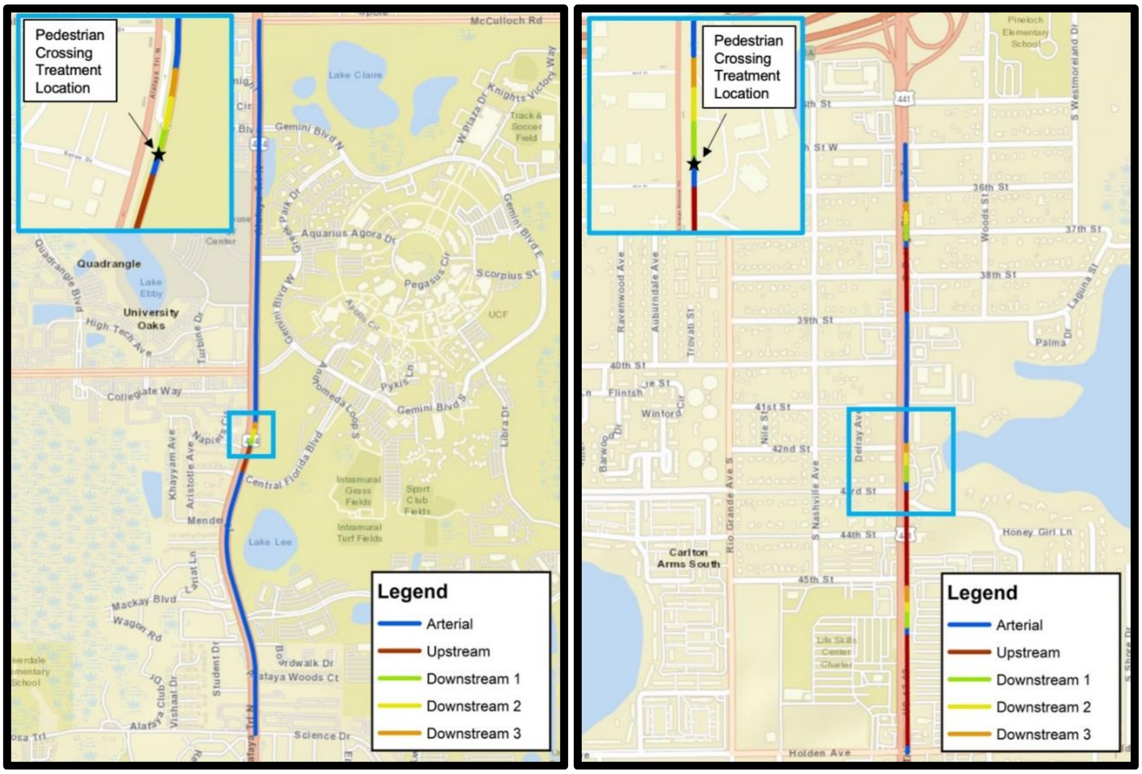


Figure 1: Northbound layout of experiment road for North Alafaya Trail (Left) and South Orange Blossom Trail (Right)

3.3. Pedestrian Crossing Treatments

The two pedestrian crossing treatments that were analyzed in the experiments were RRFB and PHB. The design and operation of RRFB and PHB in the experiments were modeled from the MUTCD, as shown in Figure 2. The phasing the PHB and the brightness and the speed of the light flashing in the RRFB were accurately reflected in the experiment. Figure 3 summarizes different phases of a PHB. When not activated, the signal is blanked out. The PHB is activated by a pedestrian through the use of a push button. Once activated, the overhead signal begins flashing yellow, followed by steady yellow, indicating that a red signal will be exhibited next. The PHB then displays a steady red to the driver and the pedestrian gets the WALK indication. After a few seconds of the pedestrian walk interval, the steady red light facing the driver begins flashing red indicating the pedestrian clearance interval and the driver may proceed if the crosswalk is clear. This sequence reduces the delay which occurs at a traditional signalized midblock crossing.

Figure 2: An activated RRFB with a pedestrian crossing (Left) and an activated PHB with a pedestrian crossing (Right)

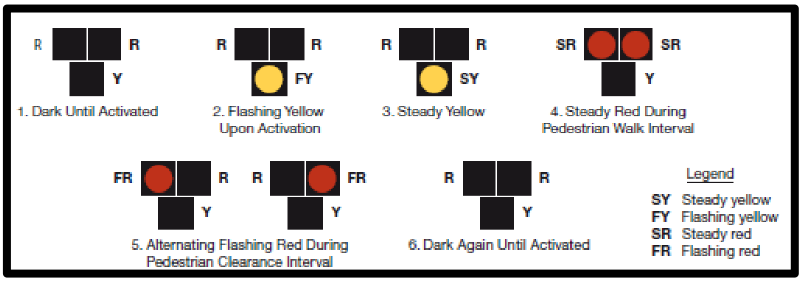


Figure 3: The phasing pattern of a PHB [14]

3.4. Summary of Scenarios

In total, 5 variables are considered in this experiment, which includes pedestrian crossing treatment type, order of pedestrian crossing treatments, roadway, direction of travel, and traffic flow setting. A total of 12 scenarios would be obtained based on the 5 variables. Each participant was assigned to the 12 different scenarios with a random order of the scenario to eliminate any bias. This design was utilized to limit time of each participant in order to reduce the probability of motion sickness. With this arrangement, each scenario had at least 36 participants, which allowed for the scenarios to be compared among each other. Table 1 summaries all the scenario and participant related variables with their respective descriptive statistics.

The speed limit of North Alafaya Trail is 45 mph, while the speed limit of South Orange Blossom Trail is 40 mph. The traffic setting was based on the traffic volume provided by the adaptive signal controllers (InSync) and vehicle speed data collected through Bluetooth detectors (BlueMAC) on the segments for both North Alafaya Trail and South Orange Blossom Trail [15].

Table 1: Descriptive statistics of independent variables

Name	Description	Input value	Count	Percentage (%)
Scenario Related Variables				
PCT_TYPE	Pedestrian crossing treatment type	PHB=1 RRFB = 0	- -	50.00 50.00
ROAD	Roadway	N Alafaya Trail = 1 S Orange Blossom Trail = 0	- -	25.00 75.00
LOCATION	Location of the analysis zone	Upstream = 1, Downstream = 0	- -	50.00 50.00
FIRST_TREATMENT	Position of the pedestrian crossing treatment is first	Yes = 1 No = 0	- -	50.00 50.00
Participant Related Variables				
GENDER	Gender	Male = 1 Female = 0	18 18	50.00 50.00
EDU	Education levels	Bachelor’s Degree = 1 Other = 0	10 26	27.78 72.22
YOUNG	Young participants (age between 18 and 24)	Yes = 1 No = 0	20 16	55.56 44.44
OLD	Old participants (age > 40)	Yes = 1 No = 0	25 11	69.44 30.56
LANE_MIDDLE	Whether the preferred driving lane is the middle lane	Yes = 1 No = 0	19 17	52.78 47.22
LANE_LEFT	Whether the preferred driving lane is the left lane	Yes = 1 No = 0	12 24	33.33 66.67

3.5. Experimental Procedure

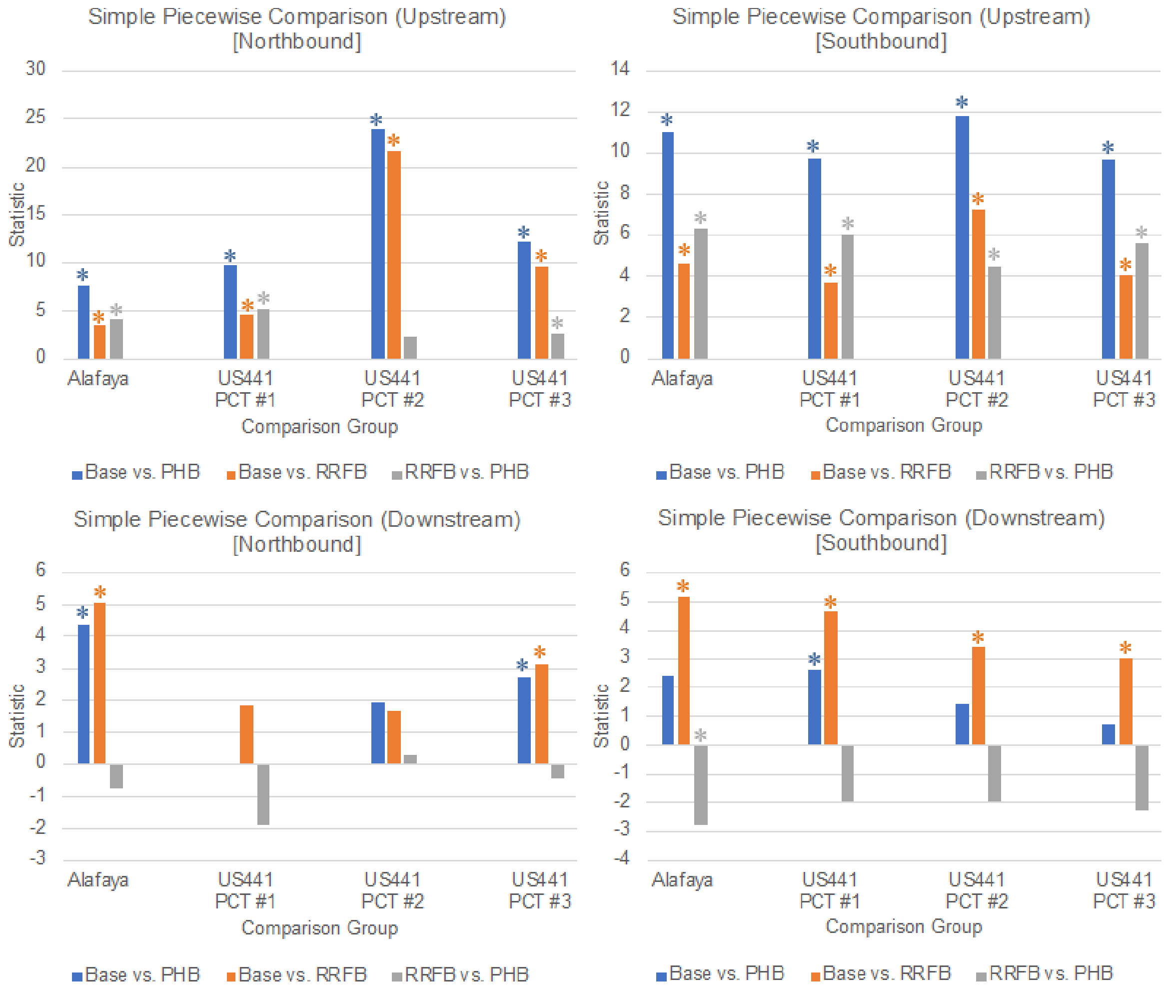
Institutional Review Board (IRB) approval was obtained before the experiment. Upon arrival at the laboratory, each participant signed a consent form and filled in a background information questionnaire. Once the participants got familiar with the apparatus in the driver’s seat, an instruction for the experiment were given. The instruction didn’t include any information about the details of experiments which may potentially influence driving behavior. Participants were instructed to drive as normally as they usually do in a real car. Then an introductory video was played for the participant in order to explain the different phases of the PHB and how to drive in a PHB and RRFB. Most participants were not familiar with the PHB so the video allowed the subjects to understand how the PHB functions. The first six scenarios would be followed by a 5-min rest period, and participants would continue the next six scenarios if they didn’t feel any negative effects of driving. Also, the participants would repeat to the driving simulator operator what each phasing of the PHB stood for, to insure they understood how to drive in a PHB.

During each trial, the participants were instructed to drive to the end of the experimental road, and the driving simulator operator would then end the experiment. Each scenario would take about 3 min and participants could have at least 5 min to rest between trials. The entire experimented lasted on average about 45 min. A total of 432 ($36 * 12$) trials were conducted.

4. Analysis and Results

The results for the ANOVA tests conducted on the mean, 85th Percentile, and maximum speed for North Alafaya Trail and US441. The results show that there are significant differences between the speed management groups (Base, RRFB, and PHB) regarding mean speed and 85th percentile speed for all roads of directions except the 1st speed management location at the southbound of US 441. The gender and age parameters were significant in some of the upstream and downstream segments. Therefore, a simple piecewise comparison is done to show the amount of difference between the speed management groups (i.e. Base, RRFB, and PHB). The differences of speed metrics between each two different speed management group are presented in Figures 4-6. The results show that both PHB and RRFB could reduce drivers' speed at the upstream of crosswalks and most downstream locations based on mean speed and 85th percentile speed. PHB is more efficient to reduce speeds than RRFB. Compared to 85th percentile speed, more speed reduction could be found for the mean speed.

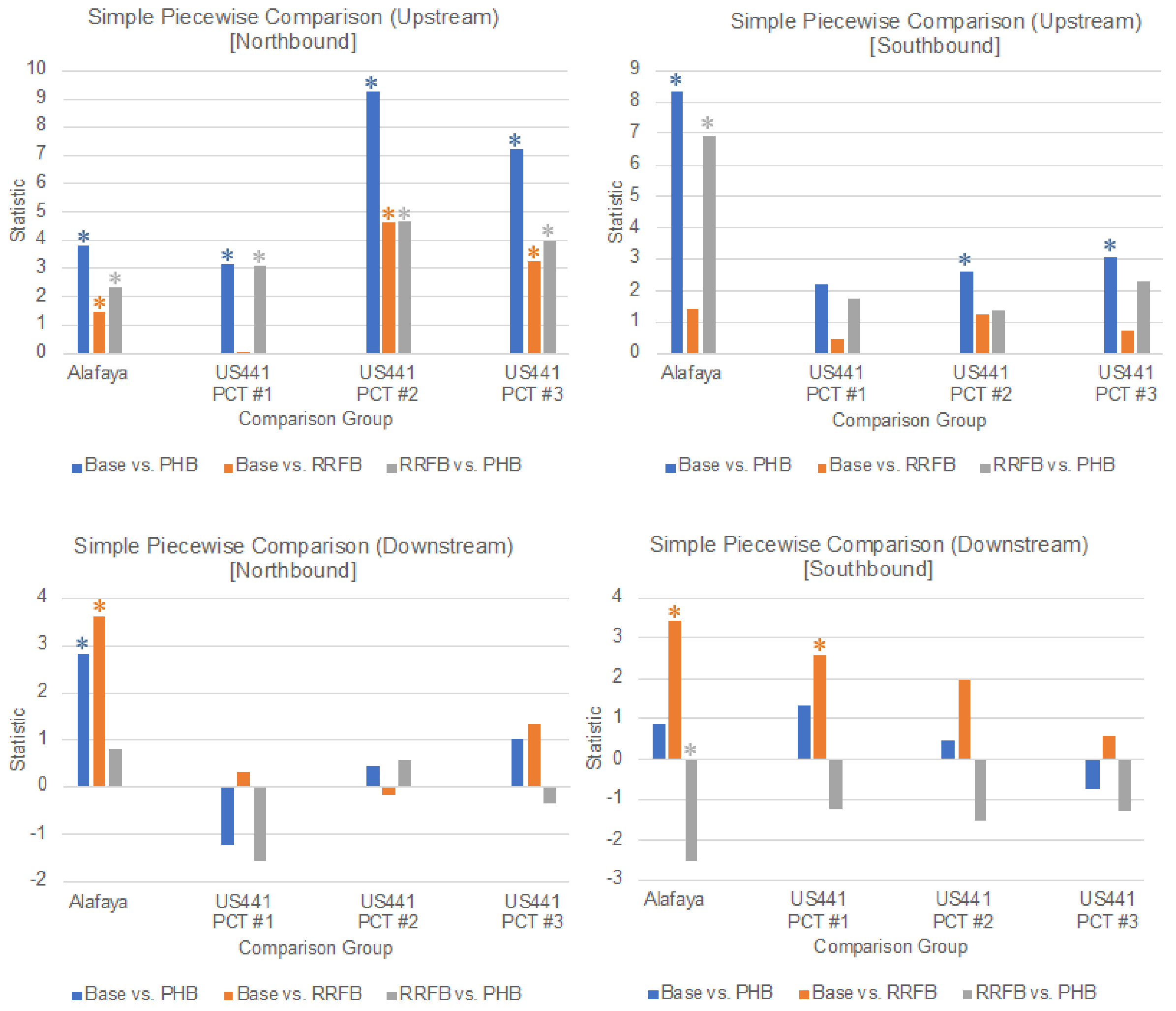
Similar results were found in Orange Blossom Trail, as the results from North Alafaya Trail. The main differences between Orange Blossom Trail and North Alafaya Trail, in term of scenario design, are that Orange Blossom Trail has a lower speed limit (40 mph) and there are three consecutive pedestrian crossing countermeasures. It could be observed that more reduction for both PHB and RRFB could be observed at the upstream on Alafaya Trail, which has a higher speed limit. Another interesting finding is that the drivers' reduced more in the second and third pedestrian crossing treatment. This may be due to the drivers' already having experience of the pedestrian crossing countermeasures in the first pedestrian crossing treatment.



* * * indicate the difference is Significant at the 90th Percentile

Note: The bar indicates the difference of mean values for each pair of groups and the bar of 'Group A vs Group B' is the 'mean value of Group A' minus the 'mean value of Group B'.

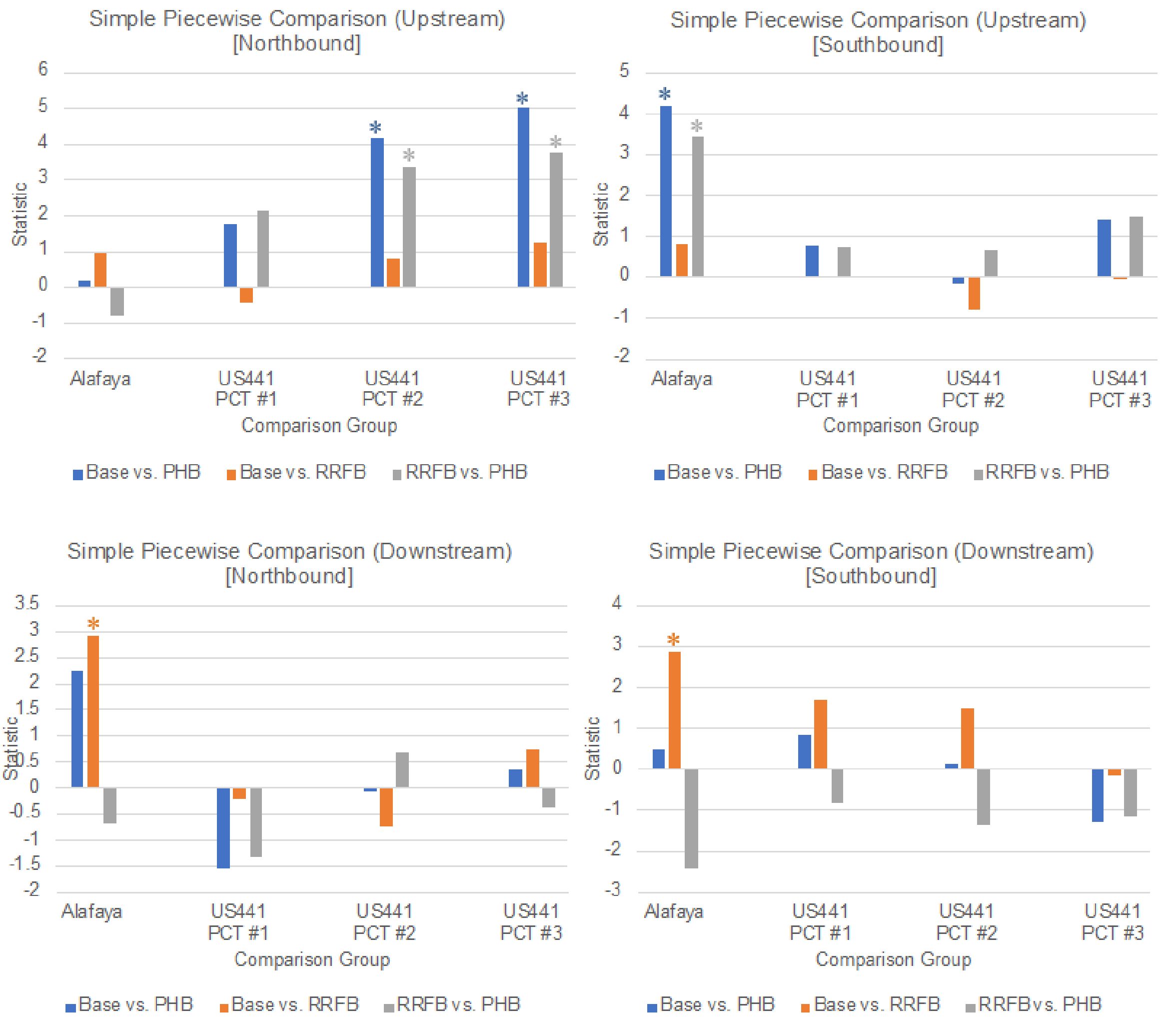
Figure 4: Difference of mean speed among different speed management groups



* * * indicate the difference is Significant at the 90th Percentile

Note: The bar indicates the difference of mean values for each pair of groups and the bar of 'Group A vs Group B' is the 'mean value of Group A' minus the 'mean value of Group B'.

Figure 5: Simple piecewise comparisons for 85th percentile speed



* * * indicate the difference is Significant at the 90th Percentile

Note: The bar indicates the difference of mean values for each pair of groups and the bar of 'Group A vs Group B' is the 'mean value of Group A' minus the 'mean value of Group B'.

Figure 6: Simple piecewise comparisons for maximum speed

5. Discussion and Conclusions

Based on the ANOVA test and Simple Piecewise Comparisons, it was shown that more reduction could be observed regarding the mean speed. Therefore, the mean speed was chosen to visualize the speed throughout the various scenarios on North Alafaya Trail and South Orange Blossom Trail is shown in Figure 7. It is clearly shown that the PHB can reduce more the speed than the RRFB for both North Alafaya Trail and South Orange Blossom Trail. The upstream of the PHB has a gradual reduction of speed when compared to the RRFB, which has a more of an abrupt change in speed. South Orange Blossom Trail has similar results to North Alafaya Trail. When the three pedestrian crossing treatment are implemented, there is an effect on the arterial at the downstream of the location of the pedestrian crossing countermeasures.

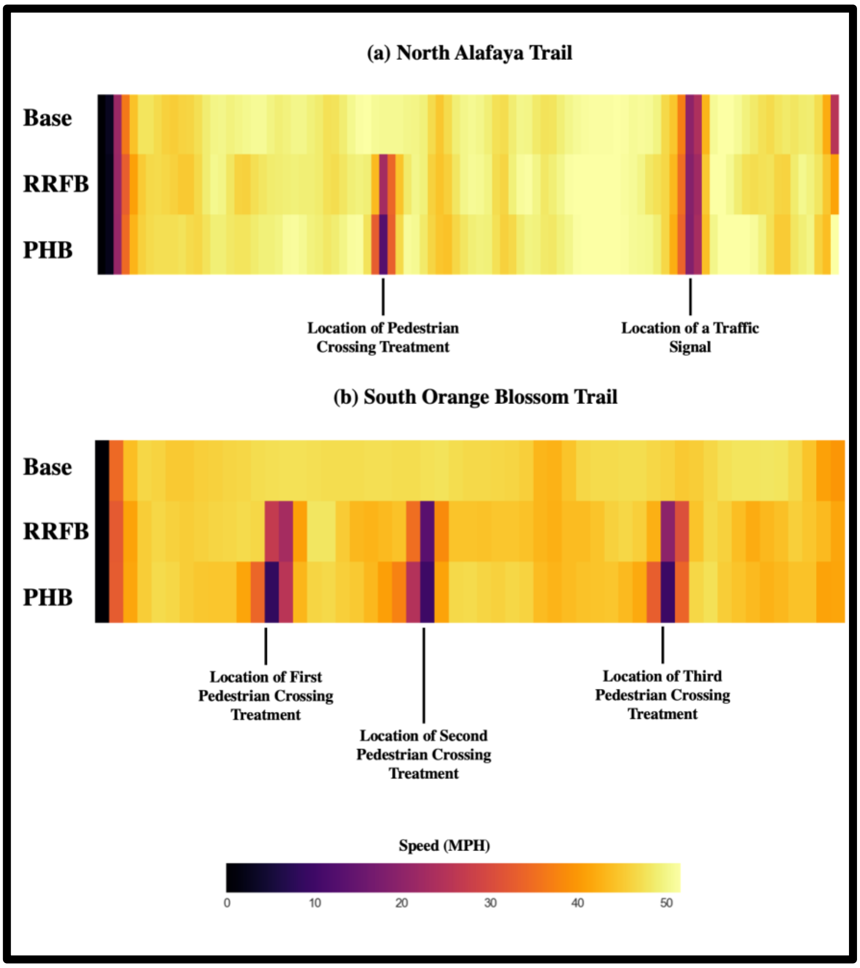


Figure 7: Average speed under different scenarios

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