MRI-2: Integrated Simulation and Safety

Year 3 – 2nd Quarterly Report

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Chapter 1: Introduction

1.1 Background

Pedestrian and bicyclist fatalities and injuries are of major concern to transportation engineers, planners, and the public. In 2011, 4,432 pedestrians were killed and an estimated 69,000 were injured in traffic crashes in the United States. This fatality rate represents an increase of 3 percent from 2010. For this same year, pedestrian deaths accounted for 14 percent of all traffic fatalities, and made up 3 percent of all the people injured in traffic crashes. Almost three-fourths (73%) of pedestrian fatalities occurred in an urban setting versus a rural setting. Over two-thirds (70%) of pedestrian fatalities occurred at non-intersections versus at intersections.

In 2011, 677 bicyclist deaths and 38,000 injuries were reported (www.nthsa.gov 2013). The total cost of bicyclist injury and death is over $4 billion per year. In 2009 the average age of bicyclists killed in crashes with motor vehicles was 41 years. 87 percent of those killed were male, and 64 percent of those killed were between the ages of 25 and 64. 13 percent of those killed in 2008 were under age 16. The average age of bicyclists injured in crashes with motor vehicles was 31 years and 80 percent of those injured were male. 51 percent of those injured were between the ages of 25 and 64; 20 percent of those injured were under age 16. The bicyclist fatality rates calculated as fatality per million population were reported to be 6.56, 0.78, and 0.46 for Florida, Tennessee, and Kentucky; respectively. The US average is reported to be 2.17.

1.2 Objectives

The fundamental objective of this research is to simulate the vehicle-pedestrian conflicts process at midblock crossings in the driving simulator and to assess the vehicle-pedestrian conflicts. Some potential risk factors were selected as the independent variables and a full factorial experiment was designed for the pedestrian-vehicle conflicts in the driving simulator. In order to analyze pedestrian-vehicle conflicts from the driver's point of view, the surrogate safety measures were examined to evaluate these pedestrian-vehicle conflicts. Specifically, this part of the major research initiative #2 (MRI-2), sponsored by the Southeast Transportation Center at the University of Tennessee as part of the University Transportation Center, is aimed at exploring the use of simulation and simulator to evaluate vehicular/pedestrian safety surrogate measures. The third year quarterly report includes the tasks 1-2.

1.3 Summary of Project Tasks

The third year STC project was designed around the following tasks:

- Task 1 Literature Search
- Task 2 Pedestrian-vehicle Prediction Model Development
- Task 3 Field Data, Simulator and Microsimulation Association
- Task 4 Final Report

The second quarterly report is the updated version for the first quarterly report. This report added the intersection experiment design and analyze the data based on the first quarterly report.

Chapter 2: Methodology

2.1 Driving Simulator

The driving simulator used in this study was located in University of Central Florida (UCF), in the United States (see Figure 1). This driving simulator is produced by NADS – the National Advanced Driving Simulator group from the University of Iowa, which provides a high fidelity driving testing environment. It is composed of a visual system (three 42" flat panel displays), a quarter-cab of actual vehicle hardware including a steering wheel, pedals, adjustable seat, and shifter from a real vehicle, a digital sound simulation system and the central console. The software, including Tile Mosaic Tool (TMT), Interactive Scenario Authoring Tool (ISAT) and Minisim, is provided for modelling the virtual road network and driving scenarios. In addition, four cameras were installed around the driving simulator to supervise the experimental process. The data sampling frequency is up to 60 Hz.

Figure 1: UCF driving simulator

2.2 Midblock Crossing Experiment Scenario Design

Previous studies in year 1 and 2 investigated some potential risk factors that affected the pedestrian safety. In this study, four potential risk factors were selected from the literature, including time of day, crosswalk marking, roadway type, and pedestrian dressing color. Each factor has two levels. Time of day include night time and daytime. Crosswalk marking represents whether the pedestrian uses crosswalk or not. Roadway type are classified into two levels, including one traveling lane with one parking lane for each direction, and two traveling lanes for each direction. Pedestrians dressing color refers to dark color clothes or bright color clothes for pedestrians.

The road network created for this study was around 3.5 miles long with the speed limit of 40 mph in urban area. The environmental vehicle flow was designed in the roadway network to make the driving scenario more realistic. In order to exclude the outside interference, there is no other vehicle in front of the simulator vehicle. This experiment utilized a within-subjects full factorial design to test four potential risk factors. There were two sub-scenarios, including daytime driving scenario and night time driving scenario. Each sub-scenario has 8 midblock crossings and drivers will encounter the pedestrian 8 times for each sub-scenario. To ensure the same approaching conditions, the distance between each midblock crossing was around 1,500 ft, which allowed drivers to reach a congruous speed for the midblock crossings.

Each pedestrian-vehicle conflict event was designed to investigate driver's avoidance behavior when drivers reacted to the pedestrian crossing. Figure 2 illustrated the pedestrian-vehicle conflict design. The road trigger was set on the road in order to realize the potential conflicts between pedestrian and simulator vehicle. When the simulator passed by this sensor, the pedestrian start to cross the street with a speed of 3.5 ft/s, which was based on Manual on Uniform Traffic Control Devices. Since each lane is 12ft wide, the distance between the pedestrian starting point and the potential conflict point is 30 ft. Based on the equation 1, the estimated distance between road trigger and the potential conflict point was 503 ft.

$$L_v = t_{ped} * V = \frac{30ft}{3.5ft/s} * 40mph = 503ft \qquad (1)$$

Therefore, when drivers passed by 503ft from the crosswalk, the road trigger is activated. The roadside pedestrian starts to cross the street. If drivers noticed the pedestrian and made a deceleration, there would be a pedestrian-vehicle conflict. In addition, participants were asked to keep in the inner lane and not to change the lane during the whole experiment period.

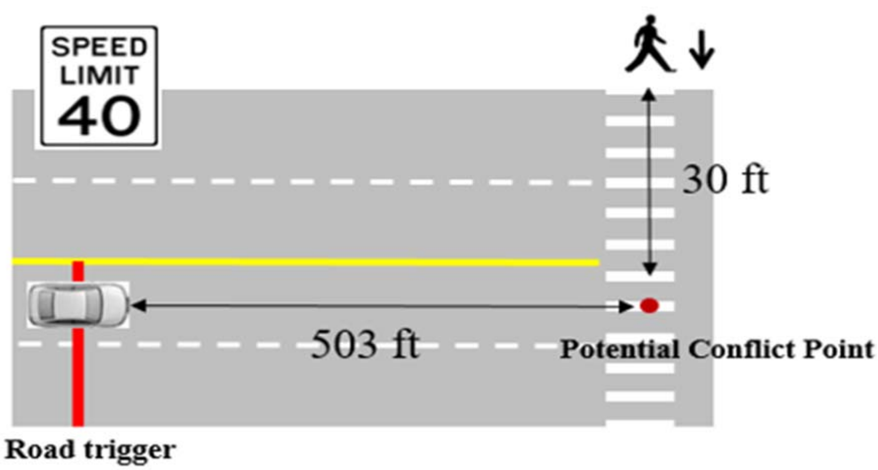


Figure 2: Scenario design for each pedestrian-vehicle conflict

2.3 Intersection Experiment Scenario Design

This experiment utilized a within-subjects repeated measures full factorial design to test potential risk factors that related to pedestrian safety at intersections. Four experimental factors are selected from the literature, including time of day, vehicle movement, pedestrian movement, and pedestrian visibility factors.

The intersection scenario was designed to investigate drivers' behaviors when drivers reacted to a potential conflict between the simulator vehicle and the pedestrian at intersections, as illustrated in Figure 3. The traffic light in this intersection has permitted left-turn signal. When the driver arrived at the intersection, the traffic light on the driver's side is always green. A pedestrian was designed to walk across the intersection at a speed of 3.5 ft/s. When the driver arrived at the stop line, a road trigger was activated. Then, the pedestrian start to cross the intersection. Meanwhile, there were no other vehicles before the simulator vehicle to interfere with the drivers' behavior and judgement.

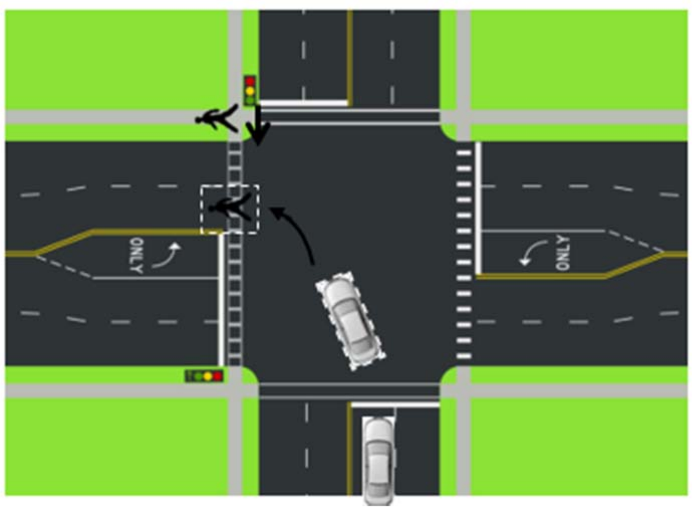


Figure 3: The intersection scenario design for pedestrian-vehicle conflict

With different factors, a total of 16 test intersections were added in this scenario. Among those, half of the intersections were in the daytime sub-scenario and the other 8 intersections were in the night sub-scenario. In each sub-scenario, the intersection with different factors was randomly assigned to the scenario. In addition, there were two additional intersections, intermingled with the test intersections. The total length of each scenario is around 3.5 miles, and participants need to drive around 10 mins to finish each sub-scenario.

2.4 Participants and Experiment Procedure

A total of 67 drivers, who had regular driver licenses, were selected to participate in this experiment. They were chosen from students, faculty, and staff of the University of Central Florida and volunteers from outside of the university. Since 8 drivers could not complete the experiment because of the motion sickness, finally, 59 drivers (28 Males and 31 females) finished the experiment successfully. In addition, all the participants were divided into two age groups. The age of the younger group ranges from 20 to 40 years. The age of the older group ranges from 40 to 60 years. Finally, 36 participants are in the younger group and 23 participants are in the older group.

Upon arrival, all participants were asked to read and sign an informed consent form (per IRB). Each participant in this study was asked to take a short training session, including the Traffic Regulation Education, the Safety Notice and the Familiarity Training. In the Traffic Regulation Education session, all participants were advised to drive and behave as they normally did and would also need to follow traffic rules as they did in real-life situations. In the Safety Notice session, each participant was told that they could quit the experiment at any time if they had any motion sickness symptoms or any kind of discomfort. In the Familiarity Training session, each participant was given at least 10 minutes training to familiarize them with the driving simulator operation, such as straight driving, acceleration, deceleration, left/right turn, and other basic driving behaviors.

After completing the short training course, participants would start the formal experiment and test two scenarios in a random sequence so as to eliminate the time order effect. In addition, all participants were recommended to rest at least 15 minutes between the scenarios.

2.5 Scenario Data Extraction

The driving simulator data included the experiment sampling time, vehicle speed, acceleration, vehicle position, steering angle and many other related parameters. The data sampling frequency is up to 60 Hz, and the collected raw data was stored in DAQ type file. The DAQ file could only be opened through Nadstools in Matlab, which was developed by NADS. First of all, DAQ files could be read through Nadstools in Matlab and then output to the EXCEL type files. In order to organize and easily process the raw data generated from the experiments, a program was developed to automatically extract the experiment data from the EXCEL files.

As for the midblock crossing scenario data collection, , researchers extracted the data from 500 ft in advance of each midblock crossing. There are two conditions that are excluded based on the pedestrian-vehicle conflict definition. First, drives didn’t yield to the pedestrian and they accelerated to pass the conflict point before the pedestrian arrived at the conflict point. Second, there is a crash between vehicle and pedestrian without the deceleration.

Therefore, 850 observations were recorded out of 944 conflict events. Among those, only 53 collisions were observed. A value of $P<0.05$ is adopted as the level for significance. The related dependent measures were defined as follows:

- Maximum Deceleration (ft/s^2): The maximum deceleration during the pedestrian-vehicle conflict period.
- Maximum Deceleration Location (ft): The distance between the conflict point and the point where the driver has the maximum deceleration during the pedestrian-vehicle conflict period.
- Minimum Distance (ft): The minimum distance between the driver and the pedestrian during the pedestrian-vehicle conflict period.
- PET (s): Post-encroachment time for the pedestrian-vehicle conflict.
- Minimum TTC (s): The minimum TTC during the pedestrian-vehicle conflict period.

As for the intersection scenario, the data were recorded starting from stop line of each intersection. However, the drivers sometimes did not yield to the pedestrian and they accelerated to pass the conflict point before the pedestrian arrived at the conflict point. Therefore, the cases illustrated above were excluded in the following analysis. Finally, 59 participants resulted in 884 experiments records. Among those, only 21 collisions were observed. A value of $P<0.05$ is adopted as the level for significance. The related dependent measures were defined as follows:

- Entrance Speed (mph): The vehicle's operating speed when the vehicle arrives at the stop line.
- Minimum Distance (ft): The minimum distance between the driver and the pedestrian during the pedestrian-vehicle conflict period.
- PET (s): Post-encroachment time for the pedestrian-vehicle conflict.
- Minimum TTC (s): The minimum TTC during the pedestrian-vehicle conflict period.

Chapter 3: Driver’s Avoidance Pattern based on Midblock Scenario

3.1 Driver’s avoidance pattern

During the pedestrian-vehicle conflict period, drivers adjust their speed by changing the deceleration rate to avoid the crash. Figure 3 shows the typical examples of drivers’ deceleration rate and the location changes. These examples exhibited a clear avoidance pattern which can be summarized into four stages, as shown in Figure 4.

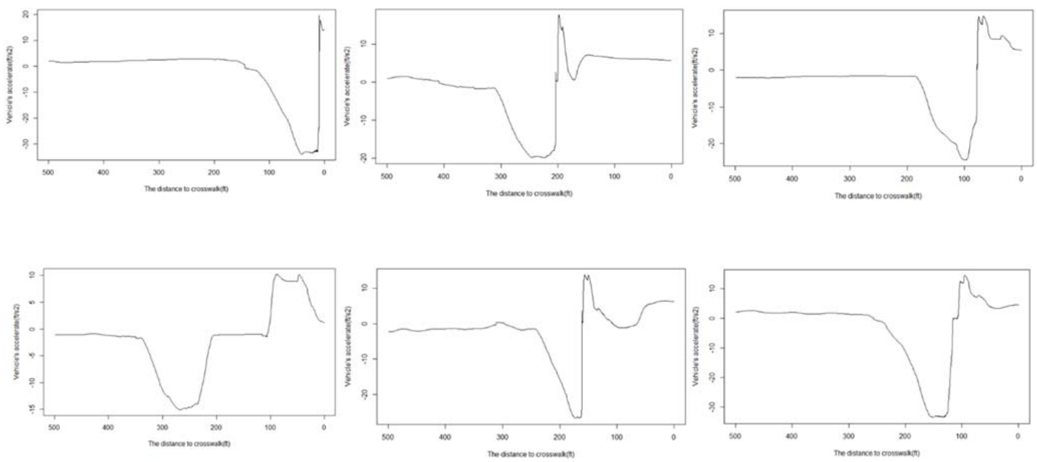


Figure 4: Drivers’ deceleration rate and the distance to crosswalk during the avoidance period

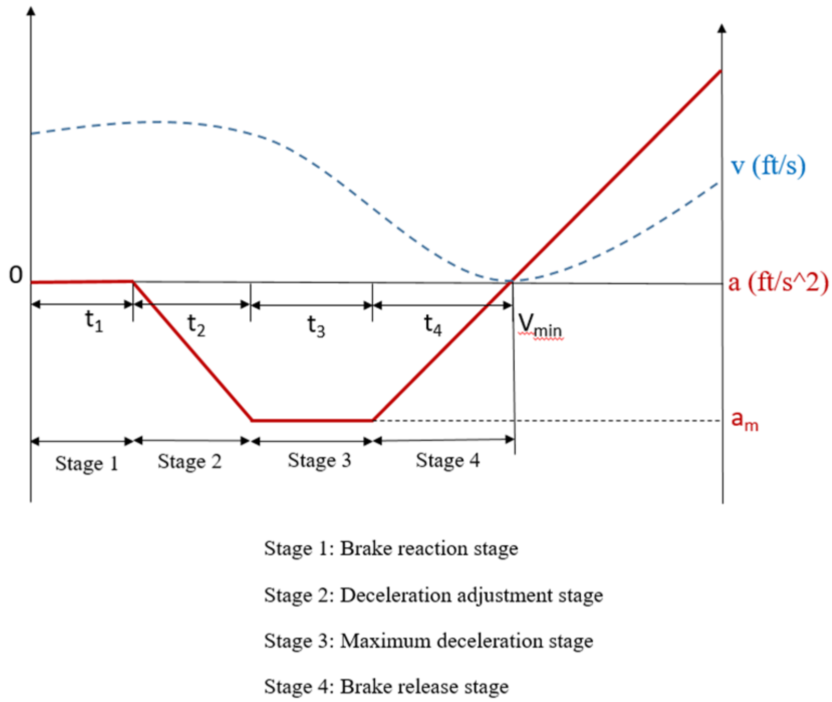


Figure 5: Drivers' avoidance pattern during the pedestrian-vehicle conflict

Stage 1: Brake reaction stage.

This stage starts from the time when drivers noticed the pedestrian crossing the street, and ended as the driver start to brake. The time duration of this stage was t_1, which was also called brake reaction time. The driver usually kept a constant initial speed during this stage. In order to get t_1, the eye tracker was usually needed. However, because of the equipment limitation, t_1 is not discussed in this study.

Stage 2: Deceleration adjustment stage

In this stage, drivers perceived the crash risk because of the sudden pedestrian appearance and then start to brake until the maximum deceleration. The time duration of this stage was t_2. In addition, the deceleration rate was assumed to be linearly increased.

Stage 3: Maximum deceleration stage

In this stage, drivers reached the maximum deceleration and stayed for a while. Drivers would release the brake until they could make sure that they won't hit the pedestrian. The duration time of this stage was t_3 and the maximum deceleration rate was d_m.

Stage 4: Break release stage

In this stage, drivers started to release the break. Finally, drivers completely stopped the car or drivers started to accelerate. The duration time of this stage was t_4.

Based on the drivers' avoidance pattern, the key variables during the pedestrian-vehicle conflict period were summarized, which include t_2 (deceleration adjustment time), t_3 (maximum deceleration time), d_m (maximum deceleration rate), and t_4 (brake release time).

3.2 Driver's behavior analysis

3.2.1 Deceleration adjustment time (t_2)

The ANOVA results of deceleration adjustment time are listed in Table 1. The AVOVA results show that four variables are significant, including age, gender, roadway type, and dressing color. Time of day and marking are not significant factors. The difference of age, gender, roadway type, and dressing color on deceleration adjustment time are shown in Figure 5. Based on the results, drivers who are under 40 years old (M = 1.44s, S.D.=1.28) had a higher deceleration adjustment time than drivers who are over 40 years old (M = 1.22s, S.D.=1.17). It seems that drivers under 40 years old are more aggressive than those over 40 years, that's why they need more deceleration time. For the gender, it appears that the mean of deceleration adjustment time for male drivers (M = 1.42s, S.D.=1.37) is higher than that for female drivers (M = 1.28s, S.D.=1.08). In other words, females drive an increased proclivity of quickly braking than male drivers. The reason is that female drivers react late in urgent situations than male drivers so that the deceleration adjustment time of female drivers become smaller than male drivers (Li et al., 2016). As for the potential risk factors, roadway type and dressing color are found to be significant with deceleration adjustment time. The deceleration adjustment time of one travelling lane with one parking lane (M = 1.39s, S.D.=1.27) is significantly higher than that of two travelling lanes (M = 1.32s, S.D.=1.22). The possible explanation is that two travelling lanes road provide the driver with more space to react than one lane road with one parking lane. Similarly, dark color clothes (M = 1.44s, S.D.=1.05) increased the deceleration adjustment time than the bright color (M = 1.27s, S.D.=1.40). When pedestrians wear the dark color clothes, drivers are difficult to find the pedestrians. Therefore, drivers need more time at the deceleration adjustment stage when pedestrian wear dark color clothes.

Table 1: Analysis of variance (ANOVA) results of deceleration adjustment time (t_2)

Variables	Df	Mean Square	F-Value	Sig.
Age	1	6.7	7.986	0.00483
Gender	1	3.8	4.534	0.03352
Time of day	1	0.3	0.382	0.53671
Marking	1	1.2	1.465	0.22650
Roadway Type	1	3.4	4.091	0.04342
Dressing Color	1	7.5	8.967	0.00283

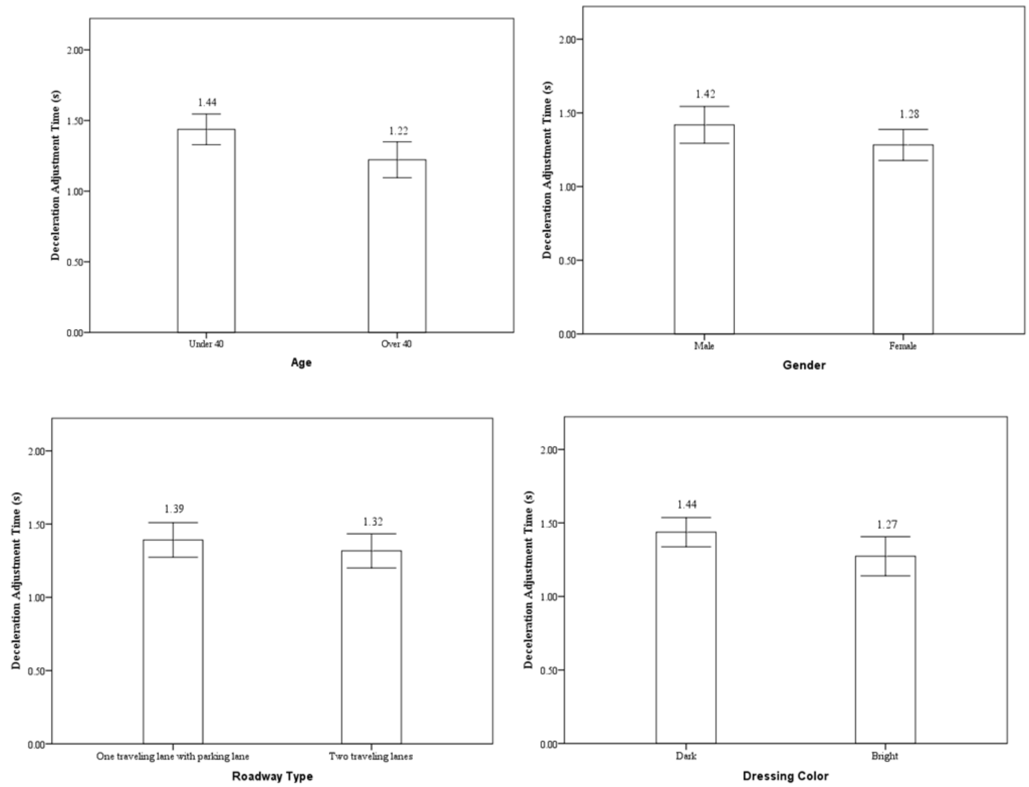


Figure 6: Relationship between deceleration adjustment time and significant factors

3.2.2 Maximum deceleration time (t_3) and maximum deceleration rate (d_m)

The basic statistical descriptions of independent variables for t_3 and d_m are listed in Table 2. Table 3 shows the ANOVA results for the maximum deceleration time and maximum deceleration rate. The ANOVA results indicate that age, gender, time of day, crosswalk marking, and dressing color have significant effect on the maximum deceleration time. However, all factors are found to be significantly associated with the maximum deceleration rate. From Table 2, it is found that if one group has a higher maximum deceleration rate, this group have a lower maximum deceleration time. For example, drivers who are over 40 years old has a higher maximum deceleration rate than drivers who are under 40 years old. However, drivers who are over 40 years old has a lower maximum deceleration time than drivers who are under 40 years old. This finding is appropriate for all variables. The lower t_3 and higher d_m implies that drivers have a relatively hard brake so that they don't need to keep the maximum deceleration for a long time. For male drivers, t_3 is 2.05 seconds and d_m is 17.04 ft/s^2. For female drivers, t_3 is 1.61 seconds and d_m is 20.00 ft/s^2. In addition, night time driving has a lower t_3 and a higher d_m than the day time driving, which indicates that drivers driving at night are more likely to have a hard brake than driving in the daytime. For the crosswalk marking, t_3 has a higher value with the marking and a lower value without a marking. Similarly, d_m has higher value without the marking and lower value with the marking. Roadway type only affects d_m, but it didn't affect t_3. Based on the results, drivers on the two lanes road have a higher maximum deceleration rate than those on the one lane with one parking lane. As for the dressing color, pedestrian with dark color clothes has a lower maximum deceleration time and a higher maximum deceleration rate. The possible reason is that when pedestrians wear bright color clothes, drivers are much easier to notice them. Therefore, they are more likely to have a hard brake, but keep a shorter period of maximum deceleration time.

Table 2: Descriptive statistics of six factors related to the t_3 and d_m

Variables		t_3		d_m	
		Mean	Std.Deviation	Mean	Std.Deviation
Age	Under 40	1.98	1.82	-17.37	8.02
	Over 40	1.64	1.51	-20.10	8.37
Gender	Male	2.05	1.84	-17.04	7.98
	Female	1.61	1.54	-20.00	8.52
Time of day	Night	1.64	1.43	-19.47	8.76
	Day	2.07	1.95	-17.32	7.79
Marking	Yes	1.95	1.69	-17.81	7.81
	No	1.74	1.74	-19.06	8.87
Roadway Type	One lane with one parking lane	1.89	1.68	-17.65	7.97
	Two lanes	1.80	1.75	-19.23	8.70
Dressing Color	Dark	1.53	1.35	-20.55	8.84
	Bright	2.16	1.97	-16.29	7.27

Table 3: Analysis of variance (ANOVA) results of maximum deceleration time (t_3) and maximum deceleration rate (d_m)

	Variables	Df	Mean Square	F-Value	Sig.
t_3	Age	1	25.47	12.806	0.0003
	Gender	1	41.63	20.824	0.0001
	Time of day	1	24.75	12.439	0.0004
	Marking	1	17.39	8.744	0.0032
	Roadway Type	1	1.57	0.787	0.3751
	Dressing Color	1	72.46	36.426	0.0001
d_m	Age	1	1493	25.283	0.0001

Gender	1	1643	27.819	0.0001
Time of day	1	712	12.064	0.00054
Marking	1	462	7.816	0.00530
Roadway Type	1	510	8.629	0.00340
Dressing Color	1	4052	68.623	0.0001

3.3.3 Brake Release Time (t_4)

The brake release time is the time between starting to release the break and the time the driver completely stops or starts to accelerate for normal driving. Table 4 represents the ANOVA results of the deceleration adjustment time. The ANOVA results show that age and dressing color are the only two factors that affect the brake release time (t_4). The difference of age and dressing color on t_4 is shown in Figure 6. Drivers who are under 40 years old have an average of 1.50s t_4 with a standard deviation of 1.23. In comparison, drivers who are over 40 years old have an average of 1.29s t_4 with a standard deviation of 0.91. It indicates that younger drivers are more likely to release the brake faster than older drivers. Moreover, dressing color is also a significant factor that influence the t_4. From Figure 6, it is found that pedestrians with dark color clothes has an average of 1.27s t_4, which is significantly lower than pedestrian with bright color.

Table 4: Analysis of variance (ANOVA) results of deceleration adjustment time (t_4)

Variables	Df	Mean Square	F-Value	Sig.
Age	1	8.827	7.198	0.007
Gender	1	3.460	2.821	0.093
Time of day	1	0.018	0.015	0.903
Marking	1	1.772	1.445	0.230
Roadway Type	1	2.403	1.959	0.162
Dressing Color	1	18.883	15.398	0.000

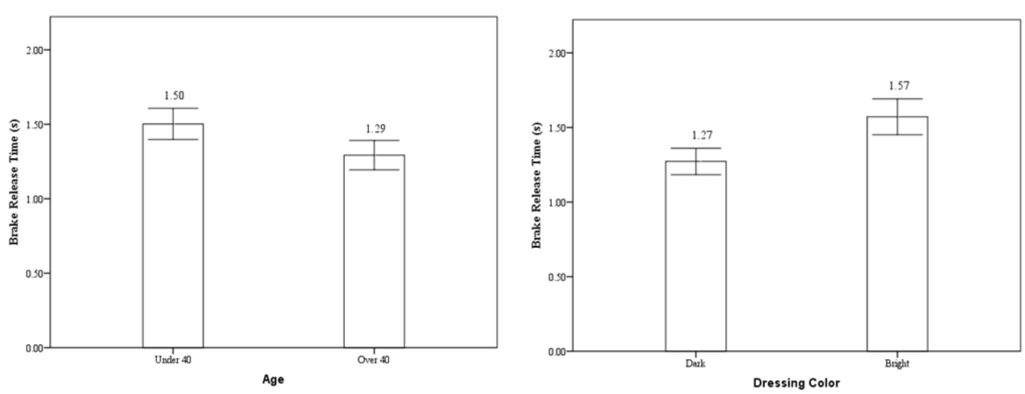
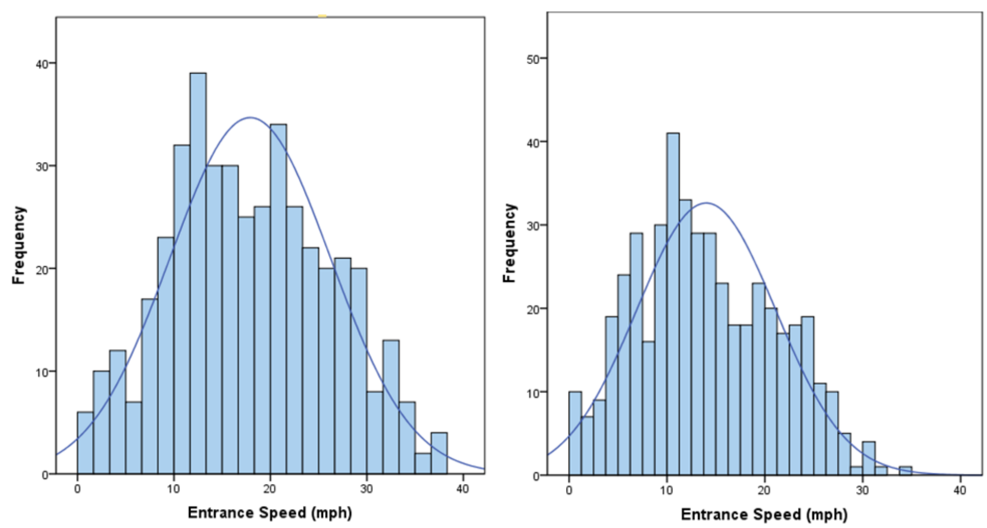


Figure 7: Relationship between brake release time and significant factors

Chapter 4: Intersection Scenario Data Analyses

4.1 Entrance Speed

Entrance speed is measured when the vehicle arrives at the stop line. For the left turns, the mean of speed is 17.90 mph with a standard deviation of 8.32; for the right turns, the mean of the speed is 14.00 mph with a standard deviation of 7.10. The histograms of the entrance speed for both left turns and right turns appear very close to normal distribution as shown in Figure 8. The average entrance speeds of left turns tend to be higher than that of right turns, presumably because the left turn has a larger radius than the right turn. The driver could have a higher speed to make left turns than right turns.



(a) The histograms of entrance speed for left turns (b) The histograms of entrance speed for right turns

Figure 8: Distribution of entrance speed for the intersection scenario

4.2 Minimum Distance

The minimum distance is still checked in the intersection scenarios. Six independent variables (age group, gender, time of day, vehicle movement, pedestrian movement, and pedestrian visibility) are chosen as potential factors that might be associated with the minimum distance of the pedestrian-vehicle conflicts and the descriptive statistics are shown in Table 5.

Table 5: Descriptive statistics of the minimum distance for the intersection scenario

Factors	Minimum distance (ft)

		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	539	25.57	10.17	14.65	45.21
	Over 40	345	26.08	10.51	14.93	46.24
Gender	Male	458	25.50	10.41	15.19	45.26
	Female	426	26.07	10.18	14.25	46.14
Time of day	Night	445	25.23	10.25	14.12	45.41
	Daytime	439	26.31	10.33	15.23	46.14
Vehicle movement	Left	430	26.54	12.04	15.08	51.89
	Right	454	24.96	8.00	14.12	38.41
Pedestrian movement	Far	452	28.66	11.86	15.64	52.56
	Near	432	23.00	7.59	14.04	36.68
Pedestrian visibility	Dark	440	23.49	7.94	14.91	37.53
	Bright	444	28.04	11.78	14.90	51.89

Running all of six given factors, Table 6 lists the mixed model results for the minimum distance. The significant main effects include the time of day, vehicle movement, pedestrian movement and pedestrian visibility. First, the results show that the minimum distance for night time is significantly smaller than that for the daytime (t=-3.05, p-value=0.0024). This tendency is in accordance with the findings in the midblock crossing scenarios. Second, the average of the minimum distance between the pedestrian and the driver for left turns is 26.54 ft, while the average of the minimum distance for right turns is 24.96 ft. The test also indicates that the minimum distance for left turns is statistically larger than that for right turns. Third, the pedestrian crossing the street from the far side has a larger minimum distance than the pedestrian crossing the street from the near side. This finding indicates that it is more dangerous for the pedestrian crossing the street from the near side than the far side. Last but not the least, the pedestrian with the bright color clothes also increases the minimum distance compared to the pedestrian with the dark color clothes. In addition, the two-way interaction vehicle movement and pedestrian visibility is also significant. Figure 9 shows the interaction effect of pedestrian visibility on vehicle movement for the minimum distance. It is found that the minimum distance for left turns are the almost the same with different pedestrian dressing color. In comparison, the pedestrian with the dark color clothes reduces the minimum distance for the right turns. The possible explanation is that it is easier for left turns to notice the crossing pedestrians because of the wider driver's view. However, for the right turns, it is hard for drivers to notice the pedestrian with dark color clothes.

Table 6: Summary of the mixed model of the minimum distance for the intersection scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	25.80	0.64	54.6	40.31	<0.0001
Time of day	0.61	0.20	817.5	-3.05	0.0024
Vehicle movement	-0.73	0.20	816.5	3.66	0.0003
Pedestrian movement	-2.8	0.20	815.6	13.90	<0.0001
Pedestrian visibility	-2.19	0.20	815.1	-10.89	<0.0001
Vehicle movement* Pedestrian visibility	3.78	0.20	815.5	18.75	<0.0001

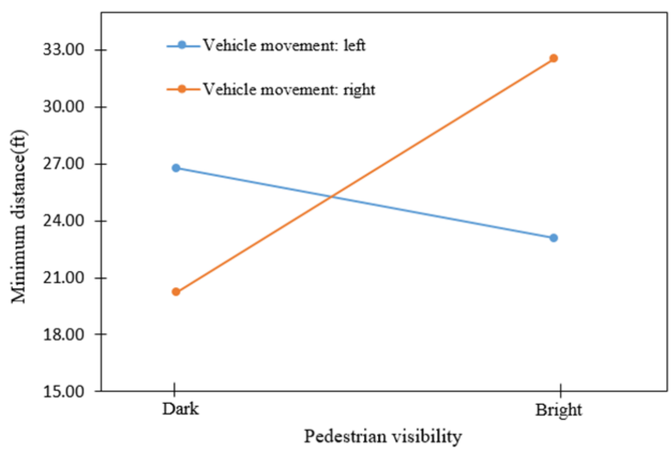


Figure 9: Interaction effect of pedestrian visibility on time of day for the minimum distance

4.3 Post encroachment time

The descriptive statistics of PET is shown in Table 7 and the summary of the mixed model for PET is shown in Table 8. The time of day and the pedestrian visibility are the only significant factors that affect PET in the intersection scenario. For the night time, the mean of PET is

6.47 seconds with a standard deviation of 4.29; for the daytime, the mean of PET is 6.05 seconds with a standard deviation of 4.10. There is a significant difference between the night time and daytime (t=1.97, p-value=0.0487). In addition, the pedestrian visibility also impacts the PET. Based on the results, it is found that the average PET of the pedestrian wearing the dark clothes is smaller than that of the pedestrian wearing the bright, indicating that drivers wait more time if the pedestrian wears the bright clothes.

Table 7: Descriptive statistics of PET for the intersection scenario

Factors		PET (sec)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	539	6.10	4.10	1.57	13.88
	Over 40	345	6.51	4.34	1.80	14.57
Gender	Male	458	5.97	4.19	1.57	13.88
	Female	426	6.57	4.18	1.67	14.40
Time of day	Night	445	6.47	4.29	1.60	14.35
	Daytime	439	6.05	4.10	1.63	13.88
Vehicle movement	Left	430	6.34	3.47	1.98	12.65
	Right	454	6.19	4.79	1.53	15.82
Pedestrian movement	Far	452	6.18	3.49	0.80	12.45
	Near	432	6.34	4.83	1.65	15.98
Pedestrian visibility	Dark	440	5.26	3.53	1.65	11.89
	Bright	444	7.25	4.56	1.13	15.98

Table 8: Summary of the mixed model of PET for the intersection scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	6.34	0.28	53.4	22.41	<0.0001
Time of day	0.24	0.12	823.6	1.97	0.0487
Pedestrian visibility	-1.00	0.12	819.4	-8.20	<0.0001

4.4 Minimum TTC

The descriptive statistics of the minimum TTC for the intersection scenario is shown in Table 9. The mixed model is still used to analyze the four potential risk factors, including age group, gender, time of day, vehicle movement, pedestrian movement, and pedestrian visibility. The results list in Table 10.

Table 9: Descriptive statistics of the minimum TTC for the intersection scenario

Factors		Minimum TTC (sec)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	539	5.52	2.63	0.72	9.99
	Over 40	345	5.74	2.53	1.52	9.92
Gender	Male	458	5.50	2.59	0.65	9.99
	Female	426	5.72	2.59	1.47	9.95
Time of day	Night	445	5.30	2.56	0.82	9.65
	Daytime	439	5.91	2.59	1.02	10.40
Vehicle movement	Left	430	5.09	2.16	1.24	8.75
	Right	454	6.09	2.86	0.82	10.63
Pedestrian movement	Far	452	6.18	2.76	0.50	10.47
	Near	432	5.00	2.26	1.01	8.56
Pedestrian visibility	Dark	440	5.74	2.68	1.56	10.42
	Bright	444	5.47	2.49	0.63	9.62

Table 10: Summary of the mixed model of the minimum TTC for the intersection scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|

Intercept	5.58	0.09	57.2	57.13	<0.0001
Time of day	-0.30	0.08	823.1	-3.74	0.0002
Vehicle movement	-0.50	0.08	829.5	-6.26	<0.0001
Pedestrian movement	0.59	0.08	826.5	7.32	<0.0001
Vehicle movement*pedestrian movement	-0.32	0.08	830.5	-4.06	<0.0001

Based on the results, it is found that time of day, vehicle movement, and pedestrian movement are significant factor that impact the minimum TTC. First, the minimum TTC of night time is 5.30 seconds with a standard deviation of 2.56, while the minimum TTC of daytime is 5.91 seconds with a standard deviation of 2.59 seconds. When driving at night, the average minimum TTC is significantly smaller compared to the daytime period (t=-3.74, p-value=0.0002). It implies that it is dangerous when the pedestrian-vehicle conflict happens at night. Second, the minimum TTC of left turns is significantly smaller than that of right turns, indicating that drivers need to pay more attention to pedestrians when they make left turns than right turns. Moreover, the pedestrian movement is also associated with the minimum TTC, which means drivers reaction to pedestrians who appear from the near side is different to pedestrians who appear from the far side. It seems that pedestrians who appear from the near side is more dangerous than pedestrians who appear from the far side. Last but not the least, the interaction effect of vehicle movement on pedestrian movement for the minimum distance is shown in Figure 10. It is found that the minimum TTCs for pedestrian-vehicle conflict of left turns are the almost the same with different pedestrian movements. In comparison, when the vehicle makes right turn, the pedestrian showing on the left side increases the minimum distance compared to the pedestrian showing on the right side. The possible explanation is that it is easier for drivers to notice the pedestrian showing on the left side other than right side.

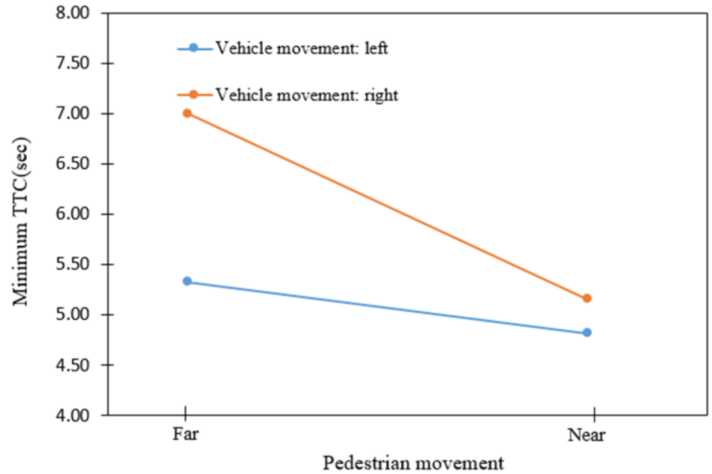


Figure 10: Plot of interactions between vehicle movement and pedestrian movement of the minimum TTC for intersection scenario

Chapter 5: Conclusions

Pedestrian-vehicle crashes happen infrequently, so it is hard to capture how pedestrian-vehicle crash occurs. However, the pedestrian-vehicle conflict methodology is an improved way to study this phenomenon. Therefore, this study investigated drivers' behaviors of the pedestrian-vehicle conflict at midblock crossings in the driving simulator. The scenarios were designed for the pedestrian-vehicle conflict with different potential risk factors. Finally, 59 subjects finished the driving simulator experiment and data were collected and analyzed.

First, driver's avoidance behavior pattern was summarized during the pedestrian-vehicle conflict. There are four stages showing that how drivers react to the pedestrian conflict, including brake reaction stage, deceleration adjustment stage, maximum deceleration stage, and brake release stage. Based on the driver's avoidance behavior pattern, four key variables are elected from the data, which include deceleration adjustment time, maximum deceleration rate, maximum deceleration time, and brake release time. Then, driver's characteristics variables (age and gender) and potential risk factors (time of day, marking, roadway type, and dressing color) were analysed to study their effect on the four key variables using the ANOVA. The results indicate that age, gender, roadway type, and dressing color have significant effect on the deceleration adjustment time. However, Time of day, and crosswalk marking has no effect on the deceleration adjustment time. In addition, age, gender, time of day, marking, and dressing color impact the maximum deceleration time. Among those, under 40 years old group, male drivers, daylight driving, crosswalk with marking, and bright color clothes increase the maximum deceleration time. On the contrary, under 40 years old group, male drivers, daylight driving, crosswalk with marking, and bright color clothes decreased the maximum deceleration rate. However, the roadway type only affects the maximum deceleration rate, and doesn't influence the maximum deceleration time. One lane with parking lane road has a higher deceleration rate than two-lane road. Last, age and dressing color are found to be significantly associated with the brake release time. Drivers who are over 40 years old have a lower brake release time than drivers who are under 40 years old. In addition, pedestrians with dark color clothes increased the brake release time than pedestrian with bright color clothes.

For the intersection scenario, time of day is an important factor that affects the drivers' behavior. According to the results, the night time driving decreases the minimum distance and the minimum TTC, indicating that the day time driving has lower risks than night time driving. Vehicle movement and pedestrian movement only have effects on the minimum distance and the minimum TTC. Moreover, the pedestrian visibility is examined to investigate the effects on the drivers' behavior. It is found that when pedestrians dress dark clothes, drivers usually have a smaller minimum distance and a small PET. This implies that it is very important for pedestrians to wear the bright color clothes, especially at night time. However, the age and gender didn't affect three surrogate measures based on the analysis.

Appendix A: IRB Approval Letter

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Ahmed E. Radwan** and Co-PI: **Hatem Ahmed Yassin Abou-Senna, Jiawei Wu**

Date: **February 22, 2016**

Dear Researcher:

On 02/22/2016, the IRB approved the following human participant research until 02/21/2017 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	Evaluating Pedestrian-vehicle Conflict Using Driving Simulation
Investigator:	Ahmed E Radwan
IRB Number:	SBE-16-12032
Funding Agency:	
Grant Title:	N/A
Research ID:	1057178

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 02/21/2017, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 02/22/2016 04:56:10 PM EST

IRB Manager