MRI-2: Integrated Simulation and Safety

Year 2 Final Report

Submitted by:

Dr. Essam Radwan, P.E. (PI), Ahmed.Radwan@ucf.edu

Dr. Hatem Abou-Senna, P.E. , habousenna@ucf.edu

Dr. Mohamed Abdel-Aty, P.E., M.Aty@ucf.edu

Jiawei Wu, wjw345178371@knights.ucf.edu

Center for Advanced Transportation Systems Simulation (CATSS)

Department of Civil, Environmental & Construction Engineering (CECE)

University of Central Florida

Orlando, FL 32816-2450

(407) 823-4738

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Executive Summary

This document serves as a report for the second year of the second major research initiative (MRI-2) and titled ‘Integrated Simulation and safety”, sponsored by the Southeast Transportation Center at the University of Tennessee as part of the University Transportation Center. The first year report documented two aspects of pedestrian simulation namely field data collection of traffic conflicts between vehicular and pedestrian traffic and the use of microsimulation to estimate pedestrian/vehicular traffic conflicts. It became clear from first year research findings that a third dimension is needed to complement this year and that is the use of a driving simulator to measure driver/pedestrian conflicts.

This study was designed to assess pedestrian-vehicle conflicts under different potential risk factors at both midblock crossings and intersections. The driving simulator data were extracted and analyzed. The potential risk factors of midblock crossings include time of day, crosswalk marking, roadway type, and pedestrian visibility. In the midblock crossing scenarios, it was concluded that night time driving not only increases the maximum deceleration, but also decreases the maximum deceleration location, the PET and the minimum TTC compared to daytime driving. All of the findings imply that the night time driving is more dangerous than the daytime driving for the pedestrian-vehicle conflicts. The marked crosswalk is also associated with the pedestrian safety. Although the marked crosswalk has nothing to do with the maximum deceleration, the minimum distance and the PET, it increases the maximum deceleration location and the minimum TTC. It was also found that when pedestrians dress dark clothes, drivers usually have a larger maximum deceleration and a small maximum deceleration location. In addition, the minimum distance, the PET and the minimum TTC of the pedestrian with the dark color clothes are also smaller than that of the pedestrian with the bright color clothes.

Similar finding in the intersection scenario were observed. Entrance speed is checked for both left turns and right turns. The histograms showed the entrance speed to follow a normal distribution. Time of day was found to impact the minimum distance, PET, and the minimum TTC. In general, 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. Besides, pedestrian visibility is also the significant factor that affects the minimum distance and the PET.

Chapter 1: Introduction

1.1 Background

In recent years, several traffic agencies have begun to put much emphasis on the importance of the pedestrian safety. In the United States, nearly 65,000 pedestrians were reported injured in 2014, nearly one injury every 8 minute. Even worse, 4,884 people were killed in pedestrian vehicle crash in 2014, more than 12 people every day of the year. It represented an increase of 9 percent compared to 2011. Although the fatality number only accounts for 3% percent of all the people injured in traffic crashes, the number of pedestrian fatalities is still to be around 15% of total traffic fatalities (Williams, 2013; National Highway Traffic Safety Administration, 2016). Worldwide, more than 270,000 pedestrians lose their lives on roads each year, accounting for 22% of the total 1.24 million road traffic deaths (World Health Organization, 2013). Overall, pedestrians are at high risk all over the world.

This document serves as a report for the second year of the second major research initiative (MRI-2) and titled 'Integrated Simulation and safety", sponsored by the Southeast Transportation Center at the University of Tennessee as part of the University Transportation Center. The first year report documented two aspects of pedestrian simulation namely field data collection of traffic conflicts between vehicular and pedestrian traffic and the use of microsimulation to estimate pedestrian/vehicular traffic conflicts. It became clear from first year research findings that a third dimension is needed to complement this year and that is the use of a driving simulator to measure driver/pedestrian conflicts.

1.2 Objectives

The main objective of this research is to assess the vehicle-pedestrian conflicts in a simulated environment at both midblock crossings and intersections using microsimulation as well as driving simulator. Several 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 is aims at exploring the use of microsimulation and driving simulator to evaluate vehicular/pedestrian safety surrogate measures. The second year report includes the tasks 6-8.

1.3 Summary of Project Tasks

The two-year project was designed around the following tasks:

- Task 1 Literature Search

- Task 2 Model Development and Testing
- Task 3 Simulation Safety Needs and Data Collection
- Task 4 VISSIM/SSAM Calibration and Validation
- Task 5 Year 1 Final Report
- Task 6 Year 2 Design of Simulator Experiment and Conduct the Experiment
- Task 7 Analyse Simulator Experiment Data
- Task 8 Year 2 Final Report

Task 6: Design of Simulator Experiment and Conduct the Experiment

A series of scenarios were designed in the UCF driving simulator to collect data on drivers' behaviors that react to pedestrian crossing the street at both mid-block crossings and intersections. Around 60 participants were recruited in the driving simulator experiment.

Task 7: Analysis Simulator Experiment Data

By processing the simulator data, appropriate measurements are extracted and used to build a model that can be used to assess the pedestrian safety surrogate measure as affected by different risk factors.

Task 8: Year 2 Final Report

This second year report documents tasks 6 and 7.

Chapter 2: Driving Simulator Experiment Methodology for Estimating Pedestrian Safety

In order to test driver's behavior towards pedestrian conflicts with different potential risk factors, this chapter documented an experiment study based on the UCF driving simulator. The purpose is to build the vehicle-pedestrian conflicts for both midblock crossings and intersections in driving simulator and to evaluate the pedestrian safety with different potential risk factors by using the traffic conflict analysis.

2.1 Driving Simulator

2.1.1 Advantages and Disadvantages of Driving Simulator Research

In recent years, the driving simulator have been widely used in the safety research. The modern driving simulator is usually built with the simulation software using a sophisticated driver environment which can give drivers on board impression that drivers feel that they drive in an actual vehicle. In addition, driving simulator usually include the visual system, audio system, and vibration system, which provide a realistic feel of all controls. Therefore, a driving simulator is one of the research tools which enables researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues (Abdel-Aty et al., 2006; Godley et al., 2002).

The use of a driving simulator for human factors research has many advantages. First, the driving simulator has controllability, reproducibility, and standardization compared to real vehicles (Yan, 2005). The behaviour of vehicles, pedestrian and other environmental conditions can be controlled based on the research purposes. Especially, the driving simulator has the ability to simulate dangerous driving situations in a safe environment, which makes researchers easier to test driving behaviors (Underwood et al., 2011; Tu et al., 2015; Yan et al., 2016; Chang et al., 2009). Second, the data can be collected accurately and efficiently (De Winter et al., 2009). Sometimes, it is difficult to collect detailed data in a real world setting. Compared to the real vehicle, the driving simulator could output the data less than a second. The researchers can get an accurate data up to 100 data points per second based on the different types of driving simulators. Third, the driving simulator can test novel instructions and functions for feedback (Yan & Wu, 2014; Yan et al., 2015; Larue et al., 2015). Some new technologies and instructions cannot be easily tested in the real vehicles because of the safety issue. Therefore, the driving simulator is an alternative to achieve the feedback of new technologies and instructions.

However, there are also some disadvantages of driving simulator researches. First, the simulator fidelity is one of factors that impact the research result. Some researches pointed out that some low-fidelity simulators may evoke unrealistic driving behaviour so that the research outcomes may be invalid (De Winter et al., 2012). In order to reduce the fidelity impact, a high-fidelity simulator is used in this study. Another important disadvantage is simulator motion sickness (Kennedy et al., 1992; Frank et al., 1988; Brooks et al., 2010). The data collected from the simulator may be bias due to the sickness symptoms. Even worse, some participants could not complete the experiments because of the motion sickness, especially for the older participants. In this study, the participant takes less than 10 mins in each scenario and they also need to have a rest between scenarios in order to alleviate the sickness problem.

2.1.2 UCF Driving Simulator

This study used a driving simulator for the experiment and data collection, which was located in University of Central Florida, 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 includes 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, can be applied for researchers to create driving scenarios with the virtual traffic environments and the virtual road networks. The data sampling frequency is up to 60 Hz. In addition, a recording system was also installed. Five cameras were installed to ensure subjects’ safety in the driving simulator and to capture the participants’ performance while driving in the simulator.

Figure 1 :UCF driving simulator

2.2 Midblock Crossing Experimental Design

2.2.1 Factors Description

This experiment utilized a within-subjects repeated measures full factorial design to test potential risk factors that related to pedestrian safety at midblock crossings. Four experimental factors are selected from the literature, including time of day, crosswalk marking, number of lanes, and pedestrian visibility factors, described in Table 1. Each factor has two levels. First, crash data show 77.2% (392 out of 508) of the pedestrians' fatalities happened during the dark time in Florida's District 5 area. Only 19.1% of the pedestrians' fatalities happened during the daylight time. Therefore, time of day is one of the most important factors included in this study. The two levels of this factor are daytime and night. Second, Zegeer et al. (2001) pointed out that the crosswalk marking was very important to the pedestrian. Those who cross the street without the marking have a higher crash rate than those who cross the street using the marking. Therefore, pedestrian crossing the street with or without the marking should be one of the potential factors. Third, almost 38% of fatal pedestrian crashes occurred on four-lane roadways and 22% of fatal pedestrian crashes occurred on two-lane roadway in Florida (Florida Department of Highway Safety and Motor Vehicles, 2010). Drivers have varying sight based on different type of roads, so gathering drivers' response with different numbers of lanes is important. In this study, two-lane road for each direction and one-lane road with one parking lane are two levels of this factor. Last, the pedestrian visibility represents the pedestrian dressing color. The literature showed that pedestrian in dark clothing were more likely to be struck. Therefore, two levels of pedestrian visibility factor are pedestrian dressing in dark color clothes or in bright color clothes. Finally, the factorial manipulation of the four factors described above resulted in 16 unique midblock crossings.

Table 1: List of factors used in the midblock crossing scenario

Factor	**Description**	**Levels**	
		Low Value (-1)	**High Value (+1)**
Time of day	Time of the day	Night	Daytime
Crosswalk marking	Pedestrian uses crosswalk	No	Yes
Roadway type	Road Geometry	One traveling lane with one parking lane for each direction	Two lanes for each direction
Pedestrian visibility	The color of the pedestrian clothes	Dark	Bright

2.2.2 Experimental Design

A within-subject design is a type of experimental design in which all participants are exposed to every treatment or condition. This experiment utilized a within-subjects full factorial design to test four potential risk factors that related to pedestrian safety at midblock crossing. Since the experiment has four factors and each factor has two levels, a total of 16 (24) different pedestrian-vehicle conflict scenarios were included in this experiment. There were two sub-scenarios in the experiment. One was the daytime driving scenario, and the other one is the night time driving scenario. Each sub-scenario contained 8 mid-block crossing and the length of each sub-scenario was around 3.5 miles. Participants need to drive around 10 mins to finish each sub-scenario. To ensure the same approaching condition, the distance between each midblock crossing was at least 1,500 ft, which allowed drivers to reach a congruous speed for the midblock crossings. The speed limit was 40 mph.

Each pedestrian crossing event was designed to investigate drivers' behaviors when drivers reacted to a potential conflict between the simulator and a pedestrian at midblock crossings, as illustrated in Figure 2. In order to create a potential conflict between the pedestrian and simulator, a road trigger was used in this scenario. The road trigger continuously evaluates the road conditions, and when they are active, they will perform the actions. First, a roadside pedestrian was designed to walk across the street at a speed of 3.5 ft/s, which was based on Manual on Uniform Traffic Control Devices (31). The distance between pedestrian and potential conflict point was 30 ft. Then the pedestrian walking time (t_{ped}) was calculated during this period:

$$t_{ped} = \frac{30ft}{3.5ft/s} = 8.57s$$

The speed limits were set at 40 mph in all roads. Therefore, the estimated distance between the road trigger and the potential conflict point (L_v) was calculated as follows:

$$L_v = t_{ped} * V = 8.57s * 40\ mph = 503\ ft$$

Therefore, the roadside pedestrian was activated to cross the street when the simulator was 503 ft away from the potential conflict point on the left side of the simulator. Meanwhile, there were no other vehicles before the simulator vehicle to interfere with the drivers' behavior and judgement. Thus, if participants kept 40 mph speed along their presumed path to the potential conflict point, there would be a pedestrian-vehicle crash. If participants noticed the pedestrian and made a deceleration, there would be a pedestrian-vehicle conflict.

To avoid the order effect on the driver's response, 3 different road scenarios with different sequence of 8 combinations of pedestrian crossings for each sub-scenario were implemented in the driving simulator. Participants were randomly assigned to one of the scenarios. Finally, each scenario had the equal number of participants.

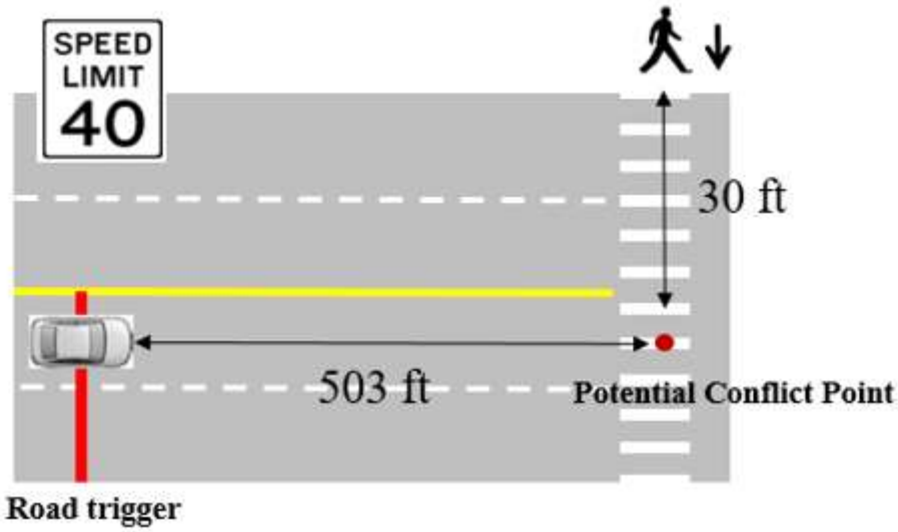


Figure 2: The midblock crossing scenario design for pedestrian-vehicle conflict

2.3 Intersection Experimental Design

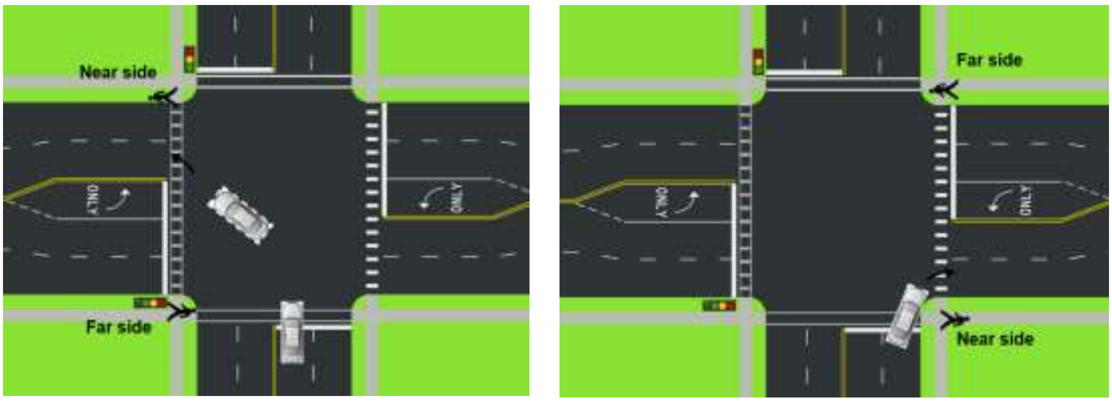
2.3.1 Factors Description

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, described in Table 2. Each factor has two levels. First, the literature pointed out that vehicle movement directions impact the pedestrian safety (Hubbard et al., 2009). Pedestrian crossing the signalized intersections may have two potential conflicts with turning vehicles: right turn on green (RTOG), and permitted left turns on green (LTOG). These potential conflicts between pedestrians and vehicles are difficult to address. In order to mitigate the pedestrian safety risk, enforcement of pedestrian right-of-way laws was applied. However, some research proved that the enforcement of pedestrian right-of-way was useless in many circumstances. Second, the pedestrian movement is also important. Different directions of pedestrian movement may affect the driver perception. Therefore, gathering driver response data with different pedestrian movement is important.

Table 2: List of factors used in the intersection scenario

Factor	Description	Levels	
		Low Value (-1)	High Value (+1)
Time of day	Time of the Day	Night	Daytime
Vehicle movement	Turning Movement	Left	Right
Pedestrian movement	Pedestrian cross the intersection from the far side or the near side[1]	Far	Near
Pedestrian visibility	The color of the pedestrian clothes	Dark	Bright

1. Pedestrian crossing the intersection from the far side means the pedestrian start point is on the far side of the intersection based on driver's location. In comparison, pedestrian crossing the intersection from the near side means the pedestrian start point is on the near side of the intersection based on driver's location. See Figure 3 for details.



(a) Left turn (b)Right turn

Figure 3：Pedestrian movement diagram

2.3.2 Experimental Design

The intersection scenario was designed to investigate drivers' behaviors when drivers reacted to a potential conflict between the driver and a pedestrian at intersections, as illustrated in Figure 4. 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.

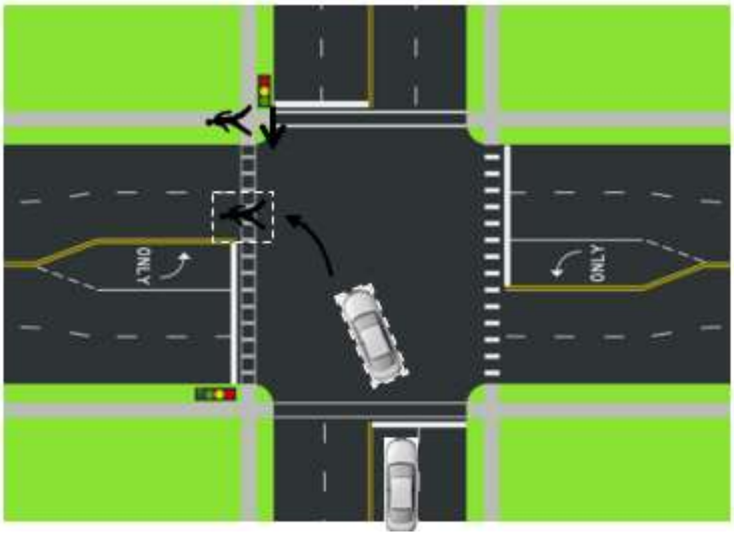


Figure 4: The intersection scenario design for pedestrian-vehicle conflict

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 Subjects

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. The distribution of the participants is shown in Table 3.

Table 3: The distribution of the participants

Age	Female	Male	Total
Under 40	16	20	36
Over 40	12	11	23
Total	28	31	59

2.5 Experiment Procedure

Upon arrival, all participants were asked to read and sign an informed consent form (per IRB), which was shown in Appendix A. 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.

2.6 Data Collection

2.6.1 Simulator Data Collection Procedure

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 (See Appendix B).

2.6.2 Midblock Crossing Scenario Data Collection

To assess the pedestrian-vehicle conflicts at midblock crossings, the data were recorded starting from 500 ft in advance of each midblock crossing. 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. Since the previous studies defined the pedestrian-vehicle conflict, which only referred to the vehicle-yield-pedestrian conflict (Parker and Zegeer, 1989), the cases illustrated above were excluded in the following analysis. Finally, 59 participants resulted in 908 experiments records. 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.

2.6.3 Intersection Scenario Data Collection

To assess the pedestrian-vehicle conflicts at intersections, 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: Driving Simulator Experiment Results and Data Analyses

3.1 Midblock Crossing Scenario Data Analyses

3.1.1 Maximum Deceleration

The mixed model was used to analyze whether the potential risk factors impacted the maximum deceleration during the pedestrian-vehicle conflict period. A mixed model is a typically statistical model, which usually contains fixed effects and random effects (Little et al., 2006). Fixed factors are the primary interests of the model and would be used again for the multiple observations per subject. Random effects are not the primary intersects, however, they are thought of as a random selection from the dataset, such as subject effect. In general, ANOVA is the common statistical models to analyze the differences among group means and their associated procedures. However, multiple measurements per subject generally result in the correlated errors that explicitly forbidden by the assumptions of ANOVA and regression models. Mixed models could handle these correlated errors by adding the fixed effects and random effects. In addition, ANOVA cannot be used when any subject has missing values, while the mixed model allows the missing values in the dataset. Therefore, the mixed model was used to analyze the relationship between independent variables and dependent variables in this study.

Four potential risk factors and two driver characteristic factors are chosen as independent variables. The four risk factors include time of day, crosswalk marking, number of lanes, and pedestrian visibility factors. Two driver characteristic factors include gender and age group. The maximum deceleration is chosen as the dependent variables. The basic statistical descriptions of experiment results are shown in Table 4. Table 5 shows final mixed model of the maximum deceleration. Hypothesis test with a 0.05 significance level is used to decide on the significant factors for the models.

Table 4: Descriptive statistics of the maximum deceleration for the midblock crossings scenario

Factors		The maximum deceleration (ft/s^2)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	555	-16.87	8.39	-34.03	-5.32
	Over 40	353	-19.35	9.07	-34.16	-7.68
Gender	Male	473	-16.70	8.40	-34.10	-7.37
	Female	435	-19.07	8.94	-34.11	-5.09
Time of day	Night	452	-19.01	9.23	-34.14	-5.35
	Daytime	456	-16.67	8.06	-34.03	-7.37
Crosswalk marking	Yes	455	-17.30	8.13	-33.99	-7.92
	No	453	-18.37	9.29	-34.13	-4.50
Roadway type	One lane	447	-17.38	8.12	-34.10	-7.98
	Two lanes	461	-18.27	9.29	-34.09	-3.86
Pedestrian visibility	Dark	456	-19.67	9.56	-34.16	-3.33
	Bright	452	-15.97	7.38	-33.94	-8.00

Table 5: Summary of the mixed model of the maximum deceleration for the midblock crossings scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	-18.11	0.53	56.1	-33.62	<0.0001
Age	1.17	0.54	56.2	2.17	0.0339
Gender	1.07	0.53	56.1	2.04	0.0465
Time of day	-1.18	0.25	848.9	-4.69	<0.0001
Pedestrian visibility	-1.85	0.25	848.3	-7.35	<0.0001

According to the results, age, gender, time of day and pedestrian visibility are significantly related to the maximum deceleration. Since there is no two-way interaction effect found between each factors for the maximum deceleration. Female drivers have a larger maximum deceleration than male drivers and drivers who are over 40 years old also have a larger maximum deceleration than drivers who are under 40 years old. The maximum deceleration of driving at night is larger than that of driving in the daytime ($t=-4.69$, p-value<0.0001). The possible reason is that drivers have low visibility when driving at night. Therefore, when they notice a pedestrian crossing the street at night, they would have a harder brake than the daytime. Moreover, the average maximum deceleration of pedestrian dressing the dark color clothes is 19.67 ft/s^2, whereas the average maximum deceleration of pedestrian dressing the bright color clothes is 15.97 ft/s^2. The final mixed model indicates that there is a significant difference between the dark color clothes and bright color clothes of the pedestrian clothes in average maximum deceleration ($t=-7.35$, p-value<0.0001). When pedestrians have the dark clothes, drivers usually have a harder brake. However, there is no interaction effect found between time of day and pedestrian visibility, indicating that pedestrians with bright color clothes contribute to the maximum deceleration no matter it is at night or in the daytime.

3.1.2 Maximum Deceleration Location

The maximum deceleration location is another measurement that can reflect the pedestrian safety. The maximum deceleration is measured as the distance between the conflict point and the point where the driver has the maximum deceleration during the pedestrian-vehicle conflict period. Four potential risk factors and two driver characteristic factors are chosen as the potential factor that might impact the maximum deceleration location. The basic statistical descriptions of experiment results are shown in Table 6. Table 7 shows final mixed model of the maximum deceleration location. Finally, all parameters' P-values are less than 0.05.

Table 6: **Descriptive statistics of the maximum deceleration location for the midblock crossings scenario**

Factors		Maximum deceleration location (ft)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	555	179.70	92.81	57.45	355.80
	Over 40	353	219.19	103.88	66.66	427.30
Gender	Male	473	172.50	91.70	52.30	355.80
	Female	435	219.57	101.09	67.24	412.37
Time of day	Night	452	172.28	85.33	51.88	286.57
	Daytime	456	217.62	106.45	71.68	424.43
Crosswalk marking	Yes	455	206.38	93.80	78.30	377.21
	No	453	183.67	103.00	47.31	420.31
Roadway type	One lane	447	185.07	85.90	68.64	344.64
	Two lanes	461	204.73	109.62	51.59	420.31
Pedestrian visibility	Dark	456	157.78	85.50	45.49	312.56
	Bright	452	232.65	97.73	88.40	424.43

Table 7: Summary of the mixed model of the maximum deceleration location for the midblock crossings

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	200.96	4.75	54.2	42.28	<0.0001
Age group	-17.54	4.76	54.3	-3.68	0.0005
Gender	-21.69	4.65	54.2	-4.66	<0.0001
Time of day	-23.31	2.51	841.4	-9.27	<0.0001
Crosswalk marking	10.69	2.51	840.6	4.26	<0.0001
Roadway type	-10.17	2.51	840.0	-4.05	<0.0001
Pedestrian visibility	-37.44	2.51	840.7	-14.90	<0.0001

The final results show that all of the main effects are significant factors. First, it is found that the maximum deceleration location of male drivers usually is nearer to the conflict point compared to female drivers (t=-4.66, p-value<0.0001). Also, younger drivers tend to brake late than older drivers. Figure 4 shows the comparison of four potential risk factors. It indicates that distance between the conflict point and the maximum deceleration location for drivers driving in the daytime is far more than that for drivers driving at night, indicating that the drivers' maximum deceleration location is near to the pedestrian at night (t=-9.27, p-value<0.0001). The crosswalk with pavement marking have a larger value of the maximum deceleration locations, indicating that the marked crosswalk could alert the drivers to brake earlier (t=4.26, p-value<0.0001). The maximum deceleration location of one-lane road is 185.07 ft far from the conflict point, whereas the maximum deceleration location of two-lane road is 204.73 ft. This finding indicates that one lane road may lead to higher pedestrian crash risk based on the maximum deceleration location. In addition, pedestrian visibility also exhibits a statistically significant effect on the maximum deceleration location (t=-14.90, p-value<0.0001). Not surprisingly, pedestrian with the dark color clothes leads to the shorter distance between the maximum deceleration location and the conflict point, which may increase the risk of the pedestrian crash.

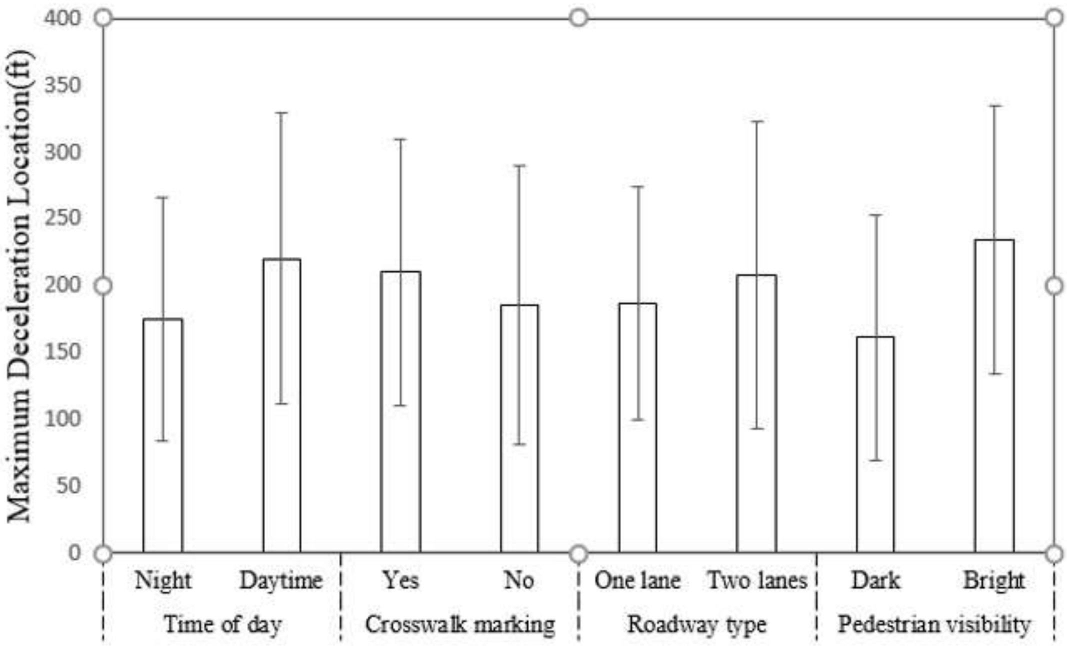


Figure 5: Comparison of maximum deceleration location of time of day, crosswalk marking, roadway type, and pedestrian visibility for the midblock crossings scenario

Moreover, four two-way interaction terms are found to be significantly related to the maximum deceleration location, which is shown in Table 8. Figure 6 shows the plots of interaction terms. First, the time of day has interaction effects with crosswalk marking and roadway type. For the night time, the maximum deceleration location of marked crosswalk is almost the same as no marked crosswalk. However, in the daytime, the marked crosswalk would increase the distance between the maximum deceleration location and the conflict point. In addition, for the night time, the maximum deceleration location for one lane roadway is almost the same as two lanes roadway. However, when the pedestrian-vehicle conflicts happen in the daytime, the maximum deceleration location of the one lane roadway is significantly lower than that of the two lanes roadway. Second, pedestrian visibility has interaction effects with crosswalk marking and roadway type. If the pedestrian wears the bright color clothes, there is no significant difference in crosswalk marking. However, if the pedestrian wears the dark color clothes, the marked crosswalk would help drivers to brake earlier than unmarked crosswalk. In addition, if pedestrian wears dark color clothes, roadway type is not related to the maximum deceleration location. However, if pedestrian wears bright color clothes, there is a significant difference in roadway type. As shown in Figure 5, it is found that drivers would make the maximum deceleration earlier on the two lanes road than one lane road.

Table 8: Summary of the interaction effects of the maximum deceleration location for the midblock crossings scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Time of day* Crosswalk marking	-5.81	2.51	840	-2.31	0.0209
Time of day* Roadway type	11.66	2.51	841.7	4.64	<0.0001
Crosswalk marking* Pedestrian visibility	11.41	2.51	840.6	4.54	<0.0001
Roadway type*Pedestrian visibility	8.24	2.51	840.0	3.28	0.0011

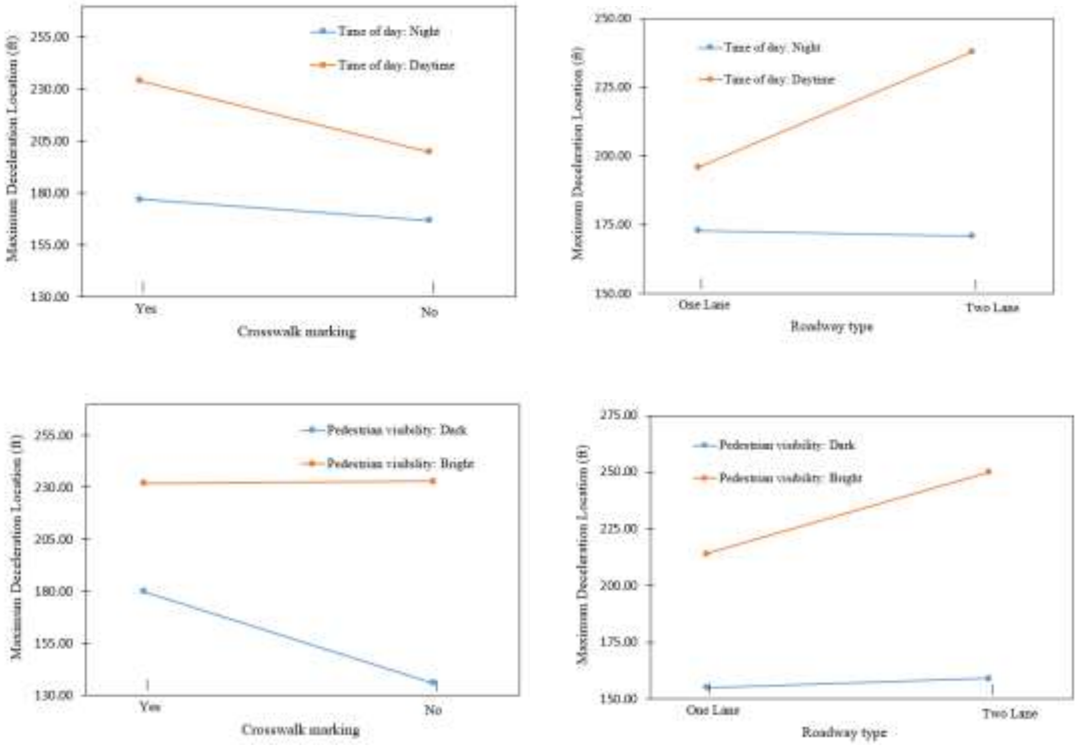


Figure 6: Plot of interactions of the maximum deceleration location for the midblock crossings scenario

3.1.3 Minimum Distance

The distance between the driver and the pedestrian changes during the pedestrian-vehicle conflict period and a minimum distance exists during this process. The minimum distance is not only used to estimate the occurrence of a collision between the driver and the pedestrian, but also used as a safety threshold reflecting the temporal buffer that drivers allow themselves for interaction with the pedestrian. Four potential risk factors (time of day, crosswalk marking, number of lanes, and pedestrian visibility factors) and two driver characteristic factors (gender and age group) are chosen as the independent variables and the minimum distance is chosen as the dependent variables. The basic statistical descriptions of experiment results are shown in Table 9. Table 10 shows final mixed model of the maximum deceleration location. Finally, roadway type and pedestrian visibility are the only significant factors. There is no interaction found in the final model.

Table 9: Descriptive statistics of the minimum distance for the midblock crossings scenario

Factors		Minimum distance (ft)				
		Count	**Mean**	**Standard Deviation**	**Percentile 05**	**Percentile 95**
Age group	Under 40	555	23.60	5.41	14.33	32.52
	Over 40	353	24.00	5.91	15.64	33.05
Gender	Male	473	23.61	5.42	14.55	32.46
	Female	435	23.91	5.81	14.49	33.68
Time of day	Night	452	23.81	6.03	13.06	32.79
	Daytime	456	23.70	5.16	15.71	33.03
Crosswalk marking	Yes	455	23.55	4.89	15.74	31.60
	No	453	23.96	6.24	13.43	34.53
Roadway type	One lane	447	23.11	4.87	15.25	31.30
	Two lanes	461	24.38	6.18	14.30	33.68
Pedestrian visibility	Dark	456	22.77	5.79	12.56	31.71
	Bright	452	24.75	5.24	16.59	33.68

Table 10: Summary of the mixed model of the minimum distance for the midblock crossings scenario

Term	**Estimate**	**Std. Error**	**DF**	**t Ratio**	**Prob>|t|**
Intercept	23.81	0.47	58.1	49.64	<0.0001
Roadway type	-0.63	0.13	846.3	-4.64	<0.0001
Pedestrian visibility	-0.99	0.13	846.5	-7.32	<0.0001
Roadway type* Pedestrian visibility	0.98	0.13	846.3	7.22	<0.0001

According to the results, the minimum distance between the driver and the pedestrian for one lane road and two lanes road are 23.11 ft and 24.38 ft, respectively. This result shows the significant difference in roadway type (t=-4.64, p-value<0.0001). The possible reason is that when drivers drive in the wide road, they are more cautious and notice the pedestrian more easily. In comparison, it is hard for them to notice the pedestrian in the narrow road, especially there is a parking lane beside the traveling lane. Therefore, the minimum distance is shorter for one lane road. Similarly, the pedestrian wearing bright color clothes have a positive impact on the minimum distance. When pedestrians wear the bright color clothes, it is much easier for drivers to notice them and take action to avoid the collision. However, when pedestrians wear dark color clothes, the minimum distance is significant shorter, which increases the risk of pedestrian crashes.

3.1.4 Post-encroachment Time

Post encroachment time (PET) is the time between the departure of the encroaching vehicle or pedestrian from the conflict point and the arrival of the vehicle or pedestrian. In this case, vehicles need to yield to the crossing pedestrian, so the pedestrian usually cross the street first and then drivers pass the conflict point. The basic statistical descriptions of experiment results are shown in Table 11. The average PET of all the pedestrian-vehicle conflicts is 6.98 seconds with a standard deviation of 2.64. The mixed model is used to check the difference between each group in PET. The results show that time of day and pedestrian visibility have significant impact on PET, which is shown in Table 12. For the night time, the mean of PET is 6.65 seconds with a standard deviation of 2.62; for the daytime, the mean of PET is 7.18 seconds with a standard deviation of 2.57. There is a significant difference between nighttime and daytime (t=-4.29, p-value<0.0001). In addition, pedestrian visibility also has significant influence on PET (t=-6.27, p-value<0.0001). The average PET of pedestrians with dark color clothes is significantly smaller than that of pedestrians with bright color clothes, which also indicates that pedestrians wearing dark color clothes have a higher risk of crash.

Table 11: Descriptive statistics of PET for the midblock crossings scenario

Factors		PET (sec)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	555	6.85	2.52	0.00	10.68
	Over 40	353	7.02	2.73	0.00	11.38
Gender	Male	473	6.81	2.49	0.00	10.67
	Female	435	7.03	2.72	0.00	11.38
Time of day	Night	452	6.65	2.62	0.00	10.68

	Daytime	456	7.18	2.57	2.80	11.22
Crosswalk marking	Yes	455	7.04	2.34	3.85	10.87
	No	453	6.79	2.84	0.00	11.38
Roadway type	One lane	447	7.00	2.29	3.97	10.67
	Two lanes	461	6.84	2.88	0.00	11.28
Pedestrian visibility	Dark	456	6.54	2.77	0.00	10.68
	Bright	452	7.29	2.37	4.13	11.08

Table 12: Summary of the mixed model of PET for the midblock crossings scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	6.95	0.23	58	29.17	<0.0001
Time of day	-0.26	0.06	847.6	-4.29	<0.0001
Pedestrian visibility	-0.39	0.06	847.4	-6.27	<0.0001

3.1.5 Time to Collision

Time to collision (TTC) has been widely used to evaluate the traffic environment in terms of safety in recent researches (Vogel, 2003; Ward et al., 2015; Shahdah et al., 2015). In this case, the minimum TTC is measured during the pedestrian-vehicle conflict. Table 13 shows the descriptive statistics of the minimum TTC. The mixed model is also used to analyze the potential risk factors and drivers' characteristics. The model results show in Table 14.

Table 13: Descriptive statistics of TTC for the midblock crossings scenario

Factors		Minimum TTC (sec)				
		Count	Mean	Standard Deviation	Percentile 05	Percentile 95
Age group	Under 40	555	4.31	1.93	0.00	7.57
	Over 40	353	5.10	2.27	0.00	9.13
Gender	Male	473	4.20	1.90	0.00	7.57

	Female	435	5.07	2.21	0.00	8.92
Time of day	Night	452	4.06	1.89	0.00	7.58
	Daytime	456	5.17	2.15	1.65	9.03
Crosswalk marking	Yes	455	4.79	1.89	1.77	8.30
	No	453	4.44	2.28	0.00	8.95
Roadway type	One lane	447	4.52	1.84	1.80	7.80
	Two lanes	461	4.71	2.33	0.00	8.75
Pedestrian visibility	Dark	456	3.90	1.99	0.00	7.23
	Bright	452	5.33	1.97	2.78	8.93

Table 14: Summary of the mixed model of the minimum TTC for the midblock crossings scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Intercept	4.75	0.15	55.3	31.58	<0.0001
Age group	-0.35	0.15	55.3	-2.35	0.0224
Gender	-0.39	0.15	55.3	-2.65	0.0105
Time of day	-0.57	0.05	838	-12.04	<0.0001
Crosswalk marking	0.14	0.05	837.8	2.84	0.0046
Roadway type	-0.09	0.05	837.5	-2.09	0.0373
Pedestrian visibility	-0.74	0.05	837.8	-15.42	<0.0001

First, age and gender have significant influence on the minimum TTC. The average of the minimum TTC of female drivers is 5.07 seconds, and the average of the minimum TTC of male drivers is 4.2 seconds. Based on the mixed model results, the minimum TTC of female drivers is significantly larger than that of male drivers, indicating that females have a lower crash risk. Similarly, the minimum TTC of drivers who are under 40 years old is significantly smaller than that of drivers who are over 40 years old. The time of day is also one of the significant factors that affect the minimum TTC. When driving at night, the average minimum TTC is 4.06 seconds with a standard deviation of 1.89. In comparison, the daytime driving increases the average minimum TTC, which is statistical significantly larger than night time (t=-12.04, p-value<0.0001). The marked crosswalk has a larger minimum TTC than unmarked crosswalk and two lanes road also has a larger minimum TTC than one lane road. Moreover, the pedestrian visibility is also associated with the minimum TTC. Pedestrians wearing dark clothes reduce the minimum TTC during the pedestrian-vehicle conflict compared to pedestrians with bright color clothes. This reduction implies that pedestrian wearing dark clothes may affect the drivers' avoidance performance and lead to the more dangerous situations. Moreover, seven two-way interaction terms are found to be significantly related to the minimum TTC, which is shown in Table 15. Figure 7 illustrates the relationship of interaction terms.

Table 15: Summary of the interaction effects of the mixed model for the minimum TTC for the midblock crossings scenario

Term	Estimate	Std. Error	DF	t Ratio	Prob>|t|
Age Group* Crosswalk marking	0.11	0.04	837.8	2.25	0.0249
Age Group * Pedestrian visibility	0.11	0.04	837.8	2.3	0.0217
Gender* Time of day	0.14	0.04	838	3.06	0.0023
Time of day* Roadway type	0.28	0.04	838.2	6.06	<0.0001
Crosswalk marking* Roadway type	0.14	0.04	837.7	3.06	0.0023
Crosswalk marking* Pedestrian visibility	0.23	0.04	837.8	4.96	<0.0001
Roadway type* Pedestrian visibility	0.18	0.04	837.5	3.88	0.0001

Age group shows interaction effects with crosswalk marking and pedestrian visibility. For the drivers who are over 40 years old, it seems that marked crosswalk doesn't affect the minimum TTC. However, if the drivers are under 40 years old, the marked crosswalk would increase the minimum TTC. The pedestrian with bright color clothes increases the minimum TTC for both younger drivers and older drivers compared to the pedestrian with the dark color clothes. The slope of the older driver group is larger than the younger driver group, indicating that bright color clothes have more effects on the older driver. For the interaction between gender and time of day, it is found that time of day have more effect on female than male, although both drivers have a larger minimum TTC in the daytime than night time. As for the interaction between time of day and roadway type, two different tendencies are found. One lane road decreases the minimum TTC than two lanes road in the daytime, however, it increases the minimum TTC than two lanes road in the night time. Moreover, there is almost no difference in the minimum TTC between marked crosswalk and unmarked crosswalk for the two lanes road. But for the one lane road, the marked crosswalk significantly increases the minimum TTC than the unmarked crosswalk. If the pedestrian wears bright color clothes, it seems that there is no difference in the minimum TTC between marked crosswalk and unmarked crosswalk.

However, the marked crosswalk significantly increases the minimum TTC than the unmarked crosswalk when the pedestrian wears dark clothes. The similar finding for the roadway type and pedestrian visibility. When the pedestrian wears dark clothes, there is almost no difference in the minimum TTC between one lane road and two lanes road. However, when the pedestrian wears bright color clothes, two lanes road have a larger minimum TTC than one lane road.

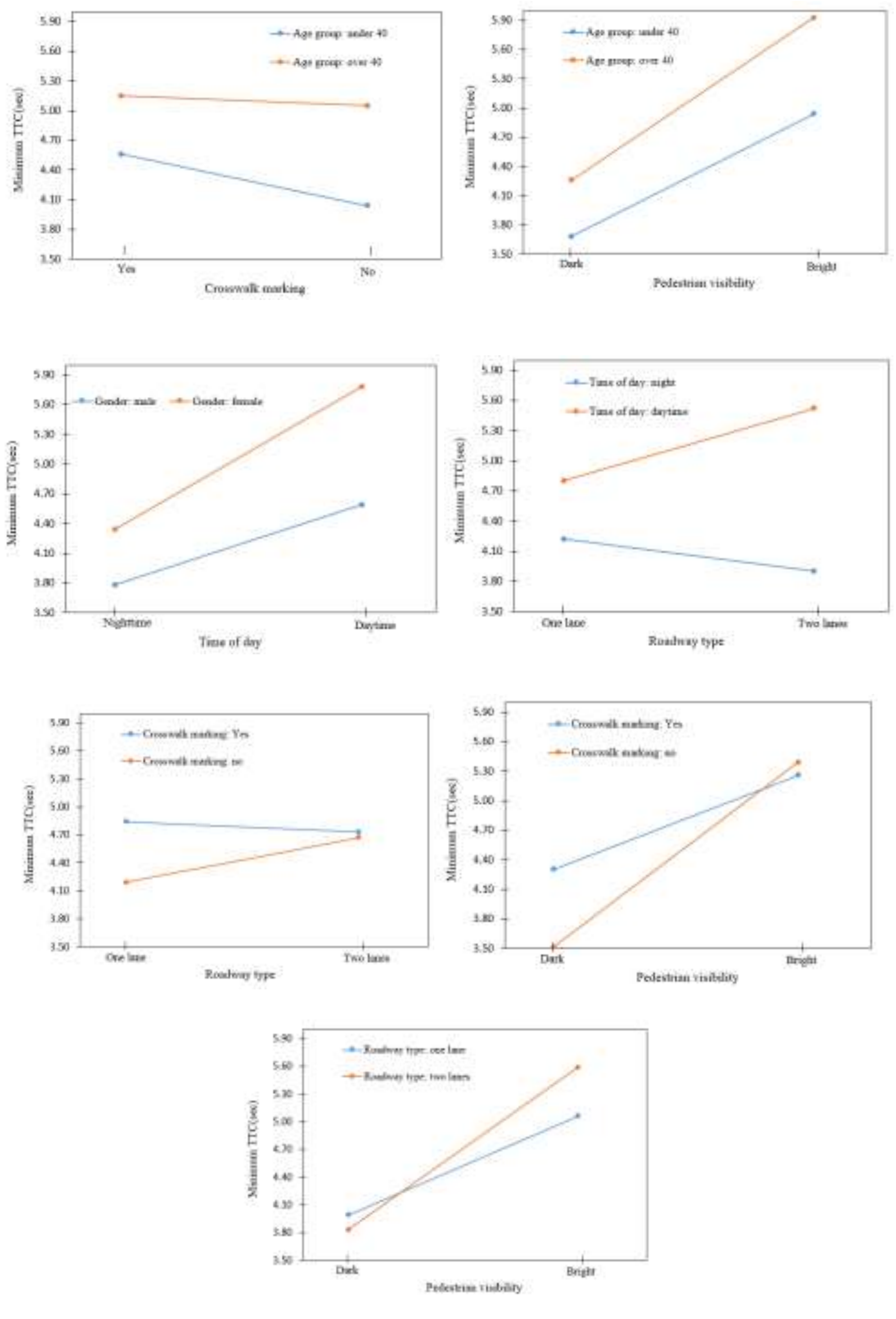
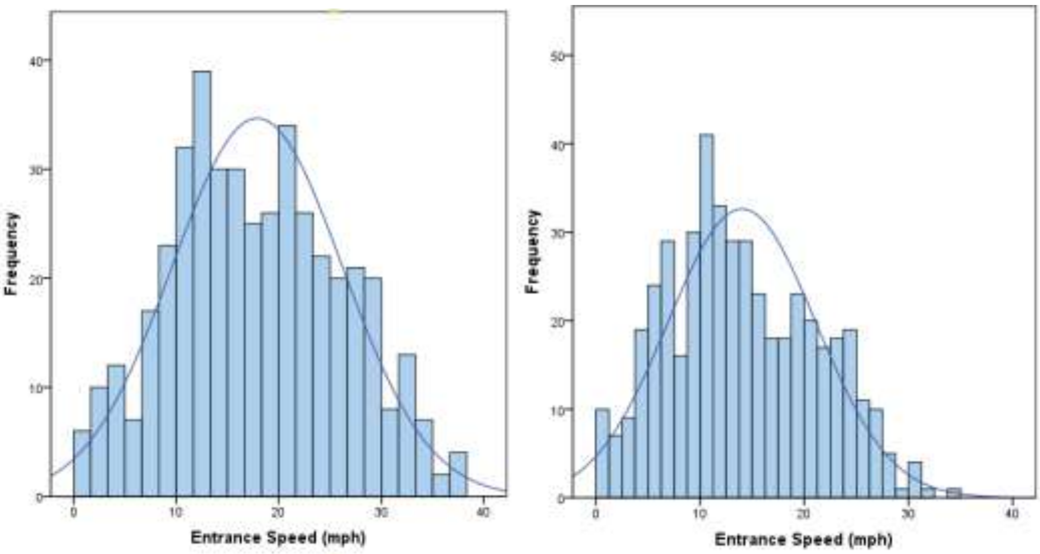


Figure 7: Plot of interactions of the maximum deceleration location for the midblock crossings scenario

3.2 Intersection Scenario Data Analyses

3.2.1 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

3.2.2 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 16.

Table 16: 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 17 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 17: 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

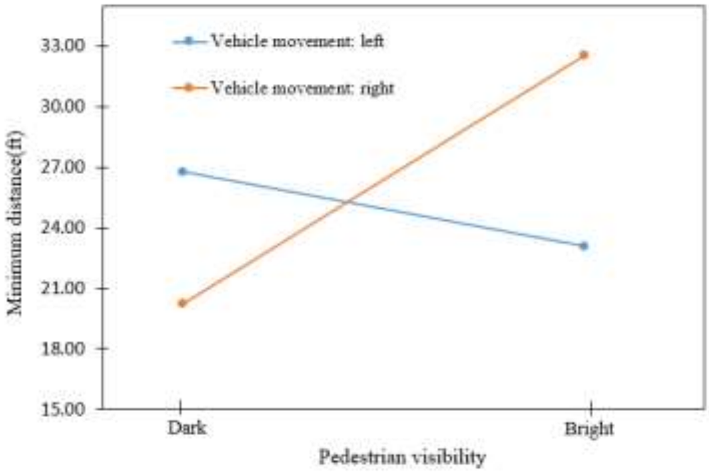


Figure 9: Plot of interactions of the minimum distance for the intersection scenario

3.2.3 PET

The descriptive statistics of PET is shown in Table 19 and the summary of the mixed model for PET is shown in Table 20. 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 18: 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 19: 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

3.2.4 Minimum TTC

The descriptive statistics of the minimum TTC for the intersection scenario is shown in Table 21. The mixed model is still used to analyse the four potential risk factors, including age group, gender, time of day, vehicle movement, pedestrian movement, and pedestrian visibility. The results list in Table 22.

Table 20: 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 21: 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.

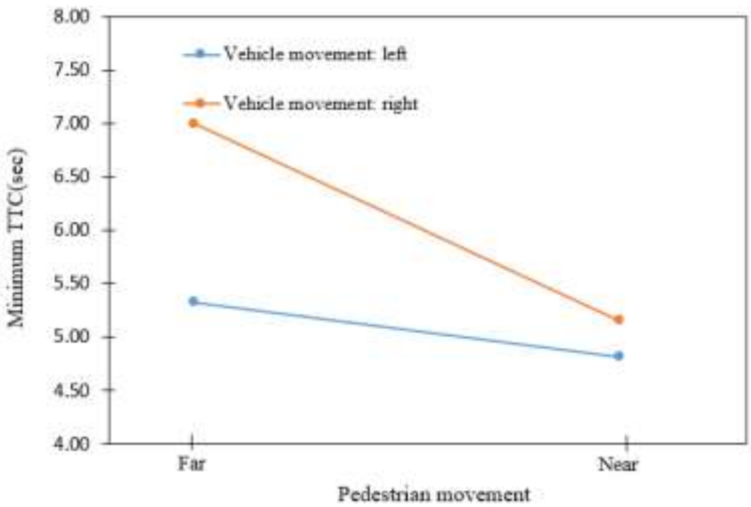


Figure 10: Plot of interactions between vehicle movement and pedestrian movement of the minimum TTC for intersection scenario

Chapter 4: Conclusions

This study was designed to assess pedestrian-vehicle conflicts under different potential risk factors at both midblock crossings and intersections. The scenarios were specifically designed for the pedestrian-vehicle conflicts in the driving simulator. The driving simulator data were extracted and analysed. Finally, the results addressed several aspects of this objective.

First, there are some findings in the midblock crossings scenario. Time of day is an important factor that affects the drivers' behaviors. According to the results, the night time driving not only increases the maximum deceleration, but also decreases the maximum deceleration location, the PET, and the minimum TTC compared to daytime driving. All of the findings imply that the night time driving is more dangerous than the daytime driving for the pedestrian-vehicle conflicts, which is in accordance with the findings of the literature (De Winter et al., 2009). The reason is that drivers have low visibility when they drive at night. Therefore, it is hard to notice pedestrians at night. When they notice the pedestrian, it is usually late compared to the daytime, which results in the dangerous situation. The marked crosswalk is also associated with the pedestrian safety. Although the marked crosswalk has nothing to do with the maximum deceleration, the minimum distance and the PET, it increases the maximum deceleration location and the minimum TTC. This finding indicates that those who cross the street without the marking have more risk than those who cross the street using the marking. Furthermore, the pedestrian safety is related to the roadway type. In this study, only two roadway types are tested in the experiment and it is found that different roadway types lead to different driving behavior for the pedestrian-vehicle conflicts. Finally, 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 larger maximum deceleration and a small maximum deceleration location. In addition, the minimum distance, the PET, and the minimum TTC of the pedestrian with the dark color clothes are also smaller than that of the pedestrian with the bright color clothes. This implies that it is very important for pedestrians to wear~~ing~~ the bright color clothes, especially at night time.

Second, there are also similar finding in the intersection scenario. Entrance speed is checked for both left turns and right turns. The histograms show the entrance speed follows the normal distribution. Then the minimum distance, PET, and the minimum TTC were analysed for seven factors. Time of day impacts on the minimum distance, PET, and the minimum TTC. In general, 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. Besides, pedestrian visibility is also the significant factor that affects the minimum distance and the PET.

In recent years, tabulation of total numbers of conflicts is used as a surrogate for safety measurement to indicate the safety issues. However, the severity of the conflicts is another element of the safety issue. This study contributed a simulator-based experiment in examining the influence of potential risk factors on surrogate safety measures to examine pedestrian-vehicle conflicts. Four potential risk factors and two drivers' characteristics were examined, including age group, gender, time of day, crosswalk marking, roadway type, and pedestrian dressing color. Accordingly, some interesting findings were found in this study.

Acknowledgement

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Appendix A: IRB Approval Letter

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:

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

IRB Manager

Appendix B: R Program to Process Experiment Data

The following code for the midblock scenario as an example show how to find key parameters from the experiment output file:

```
#Select txt

data1 = read.delim(file.choose())

#calculate the accelerate of the driver

data1$negsign = ifelse(data1$Accelerate.x.feet.sec2. > 0, 1, -1)

data1$accelerate=
sqrt(data1$Accelerate.x.feet.sec2.^2+data1$Accelerate.y.feet.sec2.^2+data1$Accelerate.z.f
eet.sec2.^2)*data1$negsign

#add the timestep in the data

Time = c(seq(from=0, to=(nrow(data1)-1)*(1/60), by=1/60))

data1$Time = Time

#subset the No.1 midblock

midblock1 = subset(data1, {X<14584 & X>13922 & Y < (-33973.9) & Y > (-34473.72)} )

#manange the No.1 midblock


speed<-midblock1[,8:27] ## column for speed

position<-midblock1[,28:87] ## column for position

c <- 1:ncol(position) ##set the

position.x<-position[,c%%3==1]    ## position of x

position.z<-position[,c%%3==0]    ## position of z

position.y<-position[,c%%3==2]    ## position of y

columnNumber<-apply(speed, 1, function(x) match(TRUE,{x>1 & x<=5}))

columnNumber<-as.numeric(columnNumber)

## Retrieve the value of speed

index2D<-function(v=columnNumber,DF=speed){

sapply(1:length(v),function(x){

   DF[x,v[x]]})
```

```
}

obj.speed<-index2D()##Output speed

obj.x<-index2D(DF=position.x)##Output position.x

obj.y<-index2D(DF=position.y)##Output speed

obj.z<-index2D(DF=position.z)##Output speed


newmidblock1<-
cbind(obj.speed,obj.x,obj.y,obj.z,midblock1$Vehicle.Speed.mph.,midblock1$Y,midblock1$X,
midblock1$Z,midblock1$Time,midblock1$accelerate)

newmidblock1<-data.frame(newmidblock1)

names(newmidblock1)<-                                                  c("obj.speed",
"object.x","object.y","object.z","Vehicle.Speed.mph.", "Y", "X","Z","Time","accelerate")

#calculate the minimum distance

newmidblock1$distance=sqrt((newmidblock1$X-
newmidblock1$object.x)^2+(newmidblock1$Y-newmidblock1$object.y)^2)

minimum.distance1 = min(newmidblock1$distance)

#calculate the PET

pettimerow              =              which(abs(newmidblock1$object.x-
14195.71)==min(abs(newmidblock1$object.x-14195.71)))

pettimecol = which(names(newmidblock1)=="Time")

pettime = newmidblock1[pettimerow,pettimecol]

PET1 = newmidblock1[nrow(newmidblock1),pettimecol]-pettime

#calculate TTC


newmidblock1$diff.y<-c(diff(newmidblock1$Y),0)

newmidblock1$diff.x<-c(diff(newmidblock1$X),0)

newmidblock1$diff.abs<-sqrt(newmidblock1$diff.y^2+newmidblock1$diff.x^2)

newmidblock1$revse.abs<-rev(newmidblock1$diff.abs)

newmidblock1$revse.cul<-cumsum(newmidblock1$revse.abs)

newmidblock1$d1ft<-rev(newmidblock1$revse.cul)#calculate cumulative distance for vehicle

newmidblock1$d1m<-newmidblock1$d1ft*0.3048
```

```
subsetofttc1<-subset(newmidblock1,{newmidblock1$object.x<14195.71&
newmidblock1$object.x>14165.63 } )#subset the newmidblock1

subsetofttc1$diff.object.y<-c(diff(subsetofttc1$object.y),0)

subsetofttc1$diff.object.x<-c(diff(subsetofttc1$object.x),0)

subsetofttc1$diff.object.abs<-
sqrt(subsetofttc1$diff.object.y^2+subsetofttc1$diff.object.x^2)

subsetofttc1$revse.object.abs<-rev(subsetofttc1$diff.object.abs)

subsetofttc1$revse.object.cul<-cumsum(subsetofttc1$revse.object.abs)

subsetofttc1$d2ft<-rev(subsetofttc1$revse.object.cul)#calculate cumulative distance for
pedestrian

subsetofttc1$d2m<-subsetofttc1$d2ft*0.3048

subsetofttc1$Vehicle.Speed.ms<-subsetofttc1$Vehicle.Speed.mph.*0.44704


subsetofttc1$vehicle.ttc.head<-(subsetofttc1$d1m-2.32)/subsetofttc1$Vehicle.Speed.ms

subsetofttc1$vehicle.ttc.tail<-(subsetofttc1$d1m+2.32)/subsetofttc1$Vehicle.Speed.ms

subsetofttc1$pedestrian.ttc<-subsetofttc1$d2m/subsetofttc1$obj.speed#condition 1

subsetofttc1$pedestrian.ttc.head<-subsetofttc1$d2m/subsetofttc1$obj.speed

subsetofttc1$pedestrian.ttc.tail<-(subsetofttc1$d2m+2.08)/subsetofttc1$obj.speed

subsetofttc1$vehicle.ttc<-(subsetofttc1$d1m-
2.32)/subsetofttc1$Vehicle.Speed.ms#condition 2

subsetofttc1$ttc <- ifelse
((subsetofttc1$vehicle.ttc.head<subsetofttc1$pedestrian.ttc)&(subsetofttc1$vehicle.ttc.tail>
subsetofttc1$pedestrian.ttc), subsetofttc1$pedestrian.ttc,
ifelse((subsetofttc1$pedestrian.ttc.head<subsetofttc1$vehicle.ttc)&(subsetofttc1$pedestria
n.ttc.tail>subsetofttc1$vehicle.ttc),subsetofttc1$vehicle.ttc,100))

#Calculate TTC and related distance

minimum.ttc1 = min(subsetofttc1$ttc)

minittcrown = which(grepl(minimum.ttc1, subsetofttc1$ttc))

minittccoln = which(names(subsetofttc1)=="d1ft")

miniposition1 = subsetofttc1[minittcrown, minittccoln]
```

```
#calculate the maximum deceleration and related position

maxdec1 = min(newmidblock1$accelerate)

maxdecrown = which(grepl(maxdec1, newmidblock1$accelerate))

maxdeccoln = which(names(newmidblock1)=="d1ft")

maxposition1 = newmidblock1[maxdecrown, maxdeccoln]

#writing results

DF.result<-
data.frame(Daylight=rep(NA),Marking=rep(NA),Roadwaytype=rep(NA),Dressingcolor=rep(N
A),Maximum.Deceleration=rep(NA),
Max.Deceleration.Location=rep(NA),Min.Distance=rep(NA),
PET=rep(NA),Min.TTC=rep(NA),Min.TTC.Location=rep(NA),    # as many cols as you need

                                  stringsAsFactors=FALSE)

#Daylight (0=dark, 1= daytime); Marking(0=no, 1=yes);Roadwaytype(0=2lane with parking, 1=
4 lanes); Dressing Color(0=Black, 1=Bright)

DF.result[1,]<-
c(NA,1,1,0,maxdec1,maxposition1,minimum.distance1,PET1,minimum.ttc1,miniposition1)
```