Before and After Study of Gainesville Pedestrian-Bicyclists Connected Vehicle Pilot

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Final Report

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16. Abstract

The Florida Department of Transportation (FDOT), along with the University of Florida (UF) and the City of Gainesville (CoG), is implementing an Accelerated Innovation Deployment (AID) Demonstration Project. The project aims to improve pedestrian and bicyclist safety at signalized intersections and mid-block crossings using connected vehicle (CV) and other innovative technologies.

The project focuses on the UF campus in Gainesville, Florida, which has high pedestrian and bicyclist traffic. It includes thirteen signalized intersections and eleven mid-block crossings. The project will deploy technologies such as Passive Pedestrian Detection (PPD) systems, Advance Vehicle Detection Systems (AVDS), Personal Information Devices (PID) (smartphones with an app), Rectangular Rapid Flashing Beacons (RRFB), Roadside Units (RSUs), Onboard Units (OBUs), and variable pedestrian phase recall applications. The project objectives are to improve pedestrian access and safety, collect data for connected vehicle performance measurement, and provide opportunities for automobile original equipment manufacturers (OEM) to introduce CV technologies.

The “before” analysis in the study area highlights key findings such as frequent jaywalking on West University Avenue, reduced jaywalking with the presence of a pedestrian/bicyclist tunnel under 13th Street, and high pedestrian density around bus stops near the Reitz Student Union building. The safety analysis examines pedestrian and bicyclist crashes, revealing patterns such as higher numbers of pedestrian crashes on Tuesdays and Fridays, with a concentration of late-night crashes along West University Avenue. The mobility study analyzes highway capacity and operational performance at selected intersections, with one unsignalized intersection showing the highest number of crashes.

To enable an effective evaluation in the next phase, the research team has taken actions such as initiating Institutional Review Board (IRB) application, developing automated performance calculation systems, and establishing data storage and processing protocols.

17. Key Words
Pedestrian and Bicyclists’ Safety, Passive Pedestrian Detection, Connected Vehicle Applications.

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Executive Summary

- The qualitative observations in the study area reveal several key findings. The study network consists of four corridors, with West University Avenue and 13th Street being the main arterial roads along with Gale Lemarand Drive and Museum Road as university local roads. Jaywalking is frequent on West University Avenue, especially during evening and night hours. The pedestrian/bicyclist tunnel under 13th Street helps reduce jaywalking in that area. Gale Lemerand Drive and Museum Road are campus streets with a lower speed limit and serve as important routes for students and staff. The Reitz Student Union building on Museum Road has high pedestrian density, particularly around bus stops. The UF football and basketball stadiums on Gale Lemerand Drive attract heavy foot traffic during events. The field survey recorded observations of signalized intersections and mid-block crossings, noting factors such as cycle failures, queue spillback, jaywalking, obstructions, presence of bus stops, and absence of bike lanes.

- The safety analysis focused on pedestrian and bicyclist crashes and examined them intersection by intersection, considering the day of the week and time of the day. The crash data, obtained from the Signal Four Analytics database, includes various details such as person type, injury severity, traffic law violations, and crash location. A total of 49 pedestrian crashes and 48 bicycle crashes were recorded between May 2014 and May 2019. The analysis reveals patterns such as higher numbers of pedestrian crashes on Tuesdays and Fridays, with a concentration of late-night pedestrian crashes along the West University Avenue corridor. In terms of bicycle crashes, Tuesdays and Wednesdays have higher numbers, and crashes are more frequent during fall and spring semesters.

- The mobility study conducted a highway capacity analysis and operational performance evaluation at three signalized intersections and one unsignalized intersection with pedestrian crosswalks. The signalized intersections chosen were located along West University Avenue, known for having a high number of pedestrian and bicyclist crashes. The unsignalized intersection selected was Museum Rd. & Reitz Union Dr., which had the highest number of pedestrian and bicycle crashes.

  Geometric data, signal timing data, and traffic flow characteristics were obtained for the analysis. Video data from cameras were used to supplement the available information. The operational analysis was conducted using the Highway Capacity Software (HCS). The results showed that the signalized intersection at W Univ. Ave. & 13th St. had a vehicular level of service (LOS) of D and other two signalized intersections had a vehicular LOS of B. The unsignalized intersection analysis included pedestrian LOS and driver yielding behavior.

- A review of pedestrian detection devices and vehicle-to-pedestrian (V2P) technologies are conducted. It discusses and summarizes the advantages and disadvantages of various sensors used for pedestrian detection, including cameras, radar, lidar, and microwave radar. The review also explores the concept of sensor fusion, where multiple sensors are combined to improve detection accuracy. Smartphone sensors are mentioned as well, highlighting their use in obtaining pedestrian position and heading. The review further discusses algorithms and datasets used for evaluating pedestrian detection methods.

- Chapter on the overview of smartphone applications for pedestrian safety discusses the use of smartphones as sensors and message delivery devices in vehicle-to-pedestrian (V2P) systems. Smartphone sensors like accelerometers, magnetometers, and gyroscopes are used for pedestrian detection and trajectory prediction. This chapter also explores pedestrian-based warnings, such as smartphone alerts, camera-based detection systems, and visual/audio instructions. The effectiveness and limitations of these warning systems are discussed.

- The research team has taken the following actions to enable an effective evaluation in Part B i.e., “After” analysis:
    - Institutional Review Board (IRB) application, which is a requirement for research involving human participants like focus groups, field experiments and surveys.
    - Development of a system to automate the process of calculating performance measures that are identified in the “before” data collection.
    - Data storage and processing protocols in collaboration with other FDOT funded projects.

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List of Acronyms

AID	Accelerated Innovation Deployment
AVDS	Advance Vehicle Detection Systems
ATMS	Advanced Traffic Management System
AWS	Amazon Web Services
AI	Artificial Intelligence
BLE	Bluetooth Low Energy
CL	Camera Lidar
CoG	City of Gainesville
ECP	EuroCity Persons
COCO	Common Object in Context
CSV	Comma-Separated Values
CAV	Connected Autonomous Vehicle
CV	Connected Vehicle
CNN	Convolutional Neural Networks
CPU	Central Processing Unit
DSRC	Dedicated Short-Range Communication
DL	Deep Learning
E-PCW	Enhanced Pedestrian Crossing Warning
ECP	EuroCity Persons
FTA	Federal Transit Administration
FAST	Features from Accelerated System
FY	Fiscal Year
FDOT	Florida Department of Transportation
FPS	Frames Per Second
GPS	Global Positioning System
GPU	Graphical Processing Unit
GUI	Graphical User Interface
ILSVRC	ImageNet Large-Scale Visual Recognition Challenge

IVP	Infrastructure and Vehicle-to-Pedestrian
KITTI	Karlsruhe Institute of Technology and Toyota Technological Institute
KAIST	Korea Advanced Institute of Science and Technology
Lidar	Light Detection and Ranging
ML	Machine Learning
MAP	Mean Average Precision
MMW	Millimeter Wave
OBU	Onboard Units
OEM	Original Equipment Manufacturers
VOC	Visual Object Class
PPD	Passive Pedestrian Detection
PSCW	Pedestrian in Signalized Crosswalk Warning
RADAR	Radio Detection and Ranging
RC	Radar Camera
RCL	Radar Camera Lidar
RRFB	Rectangular Rapid Flashing Beacons
RSU	Roadside Unit
SIFT	Scale Invariant Feature Transform
SUN	Scene Understanding
SURF	Speeded-Up Robust Features
SR	State Road
THEA	Tampa Hillsborough Expressway Authority
TTC	Time to Collision
TMC	Turing Movement Counts
TWSC	Two-Way Stop-Controlled
USDOT	United States Department of Transportation
UF	University of Florida
V2X	Vehicle to Everything
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian/Bicyclist

V2V	Vehicle-to-Vehicle
YOLO	You Only Look Once

1 Project Background

The Florida Department of Transportation (FDOT) along with the University of Florida (UF), and the City of Gainesville (CoG) is implementing an Accelerated Innovation Deployment (AID) Demonstration Project. The project is funded by an AID Grant awarded in 2017 through the United States Department of Transportation (USDOT). The UF AID, or Pedestrian-Bicycle Safety Project, will deploy and test pedestrian and bicyclist safety applications at signalized intersections and mid-block crossings using connected vehicle (CV) and other innovative technologies. This project is located at the UF campus in Gainesville, Florida. The project roadways are State Road (SR) 26 (University Avenue), US-441 (SW 13th Street), Museum Road, and Gale Lemerand Drive. The project includes thirteen (13) signalized intersections and eleven (11) mid-block crossings (some with flashing beacons). These streets have high pedestrian and bicyclist traffic with transit stops. The project will address pedestrian and bicyclist safety concerns. The emerging technologies to be deployed in this project are Passive Pedestrian Detection (PPD) systems, Advance Vehicle Detection Systems (AVDS), Personal Information Devices (PID) (smartphones with an app), Rectangular Rapid Flashing Beacons (RRFB), roadside units (RSUs), onboard units (OBUs), and variable pedestrian phase recall applications.

The study area has extensive pedestrian, bicycle, transit, and vehicle activity. The significant pedestrian and bicycle use in the study area results in conflicts with passenger cars and buses. Transit users may experience conflicts when embarking or disembarking. The project corridors (including the side streets) experienced 1,179 crashes between 2011 and 2015. These corridors also had 48 bicycle and 48 pedestrian crashes, which constitute 8 percent of the total crashes. Of the 96 bicycle and pedestrian crashes, 81 (84 percent) involved injuries.

The UF AID project aims to improve pedestrian access and safety by increasing the situational awareness of both pedestrians and drivers. The project will:

1. Facilitate dissemination of real-time traffic information to pedestrians, bicyclists, and vehicles to improve safety and operation using vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian/bicyclist (V2P) communications. This work will support FDOT's plan to accelerate emerging technology deployments to improve pedestrian and bicyclist safety, and to provide information to road users.

2. Bolster development support for UF to collect data for CV performance measurement.

3. Provide opportunities for the automobile original equipment manufacturers (OEM) to introduce CV technologies and support UF's objective to have a CV test bed for pedestrian and vehicle safety applications.

2 Project Objectives

The main objective of this project is to support the UF AID project through a multifaceted evaluation of the installed hardware and software, as well as pedestrian and bicyclist perceptions, and corridor-level operations. The software and hardware tools which aim to minimize pedestrian-bicyclist crashes by proactively alerting motorists, drivers, pedestrians, and bicyclists of the impending danger, will be deployed around the study area and evaluated. These include intersection and mid-block crossings, which will have warning or notification systems to improve pedestrian-bicyclist access and safety at the subject locations. In addition, user perception of the smartphone application provided by the selected vendor, the effectiveness of PPD systems, RRFB and other communication technologies used to assist pedestrians and bicyclists with crossing busy streets will be evaluated. Moreover, corridor-level performance in terms of safety and mobility and quantitative/qualitative evaluations of the effectiveness of the systems deployed.

3 Before Data Collection

This chapter summarizes the work conducted under the "Before Data Collection". The first subsection provides qualitative observations regarding the study area, the signalized intersections, and the mid-block crossings. The second subsection summarizes the crash data analysis based on data from Signal Four Analytics. The third subsection presents the operational analysis results using data from three signalized intersections and one unsignalized intersection with pedestrian crossings. The data were collected with video recorded from existing Bosch cameras and recently installed fisheye cameras. The fourth subsection provides the travel time and speed data obtained along one corridor (West University Avenue) of the study network.

3.1 Qualitative Observations

The study area is located around the UF campus and is adjacent to the Gainesville midtown area (Figure 1). The study network consists of four corridors in and around the campus. The mid-block crossings are denoted as C1, C2 etc. whereas signalized intersections are denoted as S1, S2 and S3 etc. These symbols are used throughout this report to reference these locations.

West University Avenue and 13th Street are arterial state roads which carry the majority of traffic to and from the campus to the rest of the city and its suburbs. Both arterial corridors have a speed limit of 30 mph. West University Avenue has several restaurants and bars that are frequented by the university staff and students during the day time. The corridor also serves as a popular night-life spot. Jaywalking on West University Avenue is frequent especially during the evening and night hours.

The 13th Street corridor is a part of the historic US 441 highway that separates the main campus from several university buildings and facilities (Norman Hall, soccer field, parking and sorority houses) and apartment complexes. Inner Road and Museum Road are frequently used by students who walk and bike to and from campus. The pedestrian/bicyclist tunnel under 13th Street helps connect the two areas and reduces jaywalking in its vicinity.

Gale Lemerand Drive and Museum Road are campus streets with a speed limit of 20 mph (campus-wide speed limit). All the mid-block crossings to be evaluated for this project are located along those two streets and they serve large numbers of students and staff traversing the campus.

The Reitz Student Union building is located on Museum Road, and it is served by a parking garage and parking lots on both sides of Museum Road. Several major bus stops are located in its vicinity. This area has one of the highest pedestrian densities on campus, along with slow moving vehicular and bus traffic.

Both the UF football and basketball stadiums are located on Gale Lemerand Drive. During events such as game days, graduation or other cultural events, the crosswalks on this road are heavily used. On non-event days most of the foot-traffic is university staff accessing the parking garage and parking lot on the west side of Gale Lemerand Drive.

At the beginning of the study, the research team conducted a field visit to record existing conditions from the perspective of pedestrians. Observers walked along the study network and took pictures of relevant elements within the area. This part of the data collection took place on Friday, September 13, 2019, 3:00 pm to 5:30 pm. The time of this data collection was selected to take place during a Friday afternoon, which has been found to generally have a high number of crashes. The direction of the walkthrough is shown in Figure 1, where A is the starting point (immediately south of the football stadium) and C is the endpoint, walking clockwise via point B on west end of Museum Road.

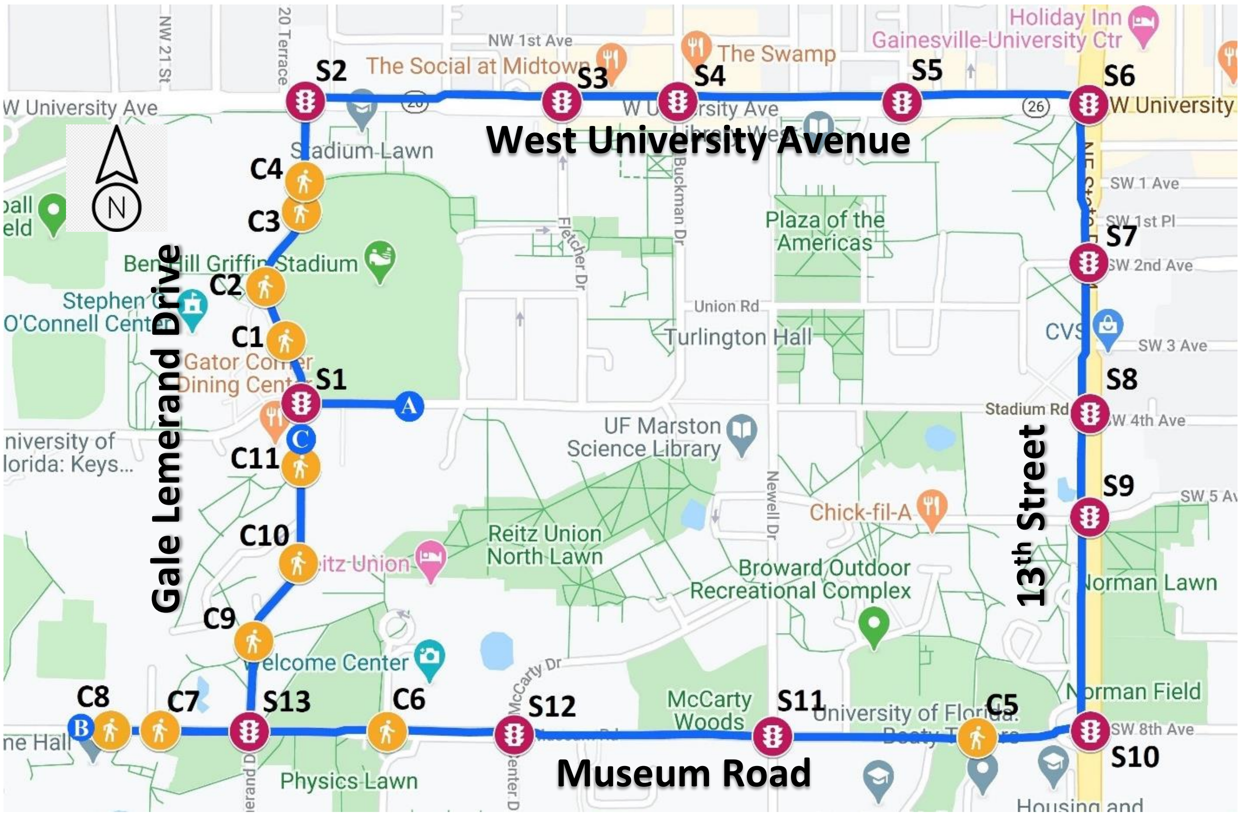


Figure 1 Study network and subject signalized intersections and mid-block crossings

3.1.1 Signalized Intersections

There are 13 signalized intersections in the project network. Two of them are three-legged or "T" intersections and the remainder are four-legged. There are five signals along West University Avenue and four more signals along 13th St.

The following were visually observed and recorded by our pedestrian observers: cycle failures, queue spillback, jaywalking, obstructions to sight distance, crossing stripe type, whether vehicles cross stop bar when stopped, presence of bus stop near the intersection, presence of bike lanes. Photographs were collected from each corner to document the geometry and status of each intersection. For example, Figure 2 shows the intersection of W Univ. Ave. and 13th St. (S6) captured from all four corners. Pictures of each intersection along with summaries of these preliminary observations are included in Appendix A.

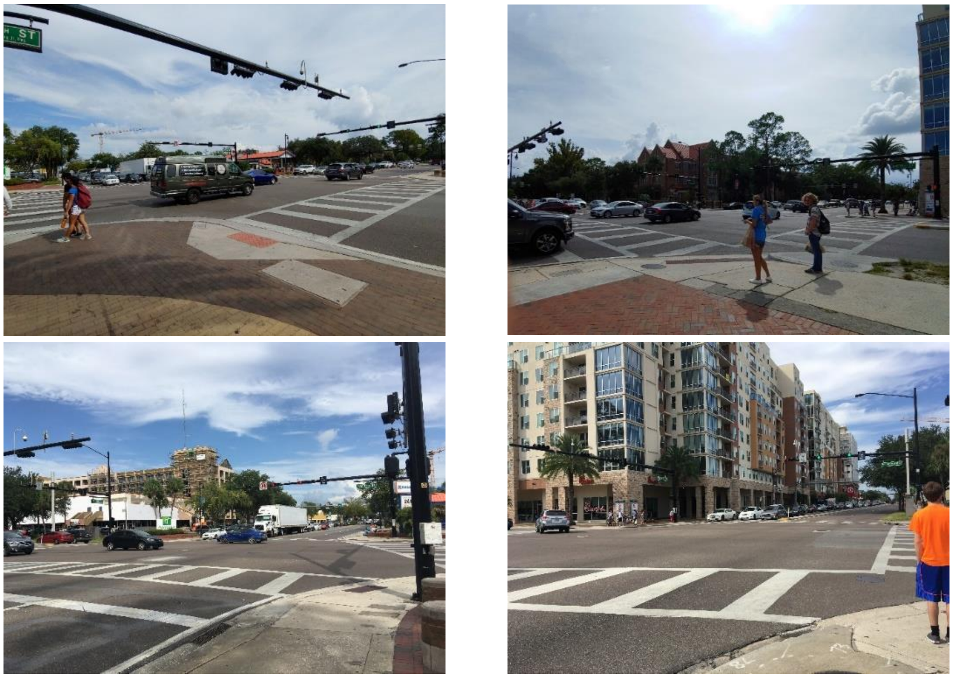


Figure 2 Photos of the intersection at W Univ. Ave. & 13 St. (S6)

Table 1 summarizes the recorded characteristics for all signalized intersections. The first column and second column of the table represent the signal ID and their locations respectively. The contents for each column are as follows:

- **Absence of Push Button:** "Y" indicates absence of pedestrians' push buttons.
- **Jaywalking:** "Y" indicates that there was at least one instance of jaywalking during our observation.
- **Pedestrian Signal Violation:** "Y" indicates there was at least one instance where the pedestrians would ignore a stop (or red) signal at a signalized intersection and walk.
- **Cycle Failure**: Cycle failure occurs when one or more vehicles have to wait for more than one cycle to discharge from an approach. Approximately 2 to 3 signal cycles were observed at each intersection. "Y" indicates there was at least one cycle failure occurrence during the observation time.
- **Queue Spillback:** Queue spillback occurs when the queue length extends to the upstream intersection. "Y" indicates there was at least one observation with queue spillback.
- **Obstruction:** "Y" indicates trees, buildings and other obstacles are present which may either block pedestrians'/bicyclists' view of arriving vehicles or vehicles' view of pedestrians/bicyclists. This type of obstruction was defined to occur when the distance between the obstacle(s) and the crosswalk was less than 15 ft.
- **Unmarked Crosswalk Stripe:** This field indicates whether the crosswalks of the signalized intersections were striped or not. "Y" indicates there are no crosswalk stripes.
- **Stop Bar Violation:** "Y" indicates at least one vehicle crossed the stop bar and occupied the crosswalk during the observation period.

- **Presence of Bus Stop:** "Y" indicates there is at least one bus stop within 100 ft from the stop bar of any approach at the intersection.
- **Absence of Bike Lanes:** "Y" indicates there are no bike lanes along any of the approaches.
- **Overall Assessment:** The overall quality of the intersection was assessed for each location based on the information in the previous columns. A value of 1 or 0 is provided for each of the characteristics ("Y" = 1, "N" = 0) observed based on the positive or negative influence on safety and mobility of an intersection. For example, jaywalking has negative impact on safety and mobility thus a value of 1 was assigned when jaywalking occurred and a value of 0 is assigned when jaywalking did not occur. The final score was determined by adding the scores of individual characteristics. Higher scores indicate a higher number of potential hazards for pedestrians at the intersection.

Table 1 Summary of qualitative observations by signalized intersection

ID	**Name**	**Absence of push button**	**Jaywalking**	**Pedestrian signal violation**	**Cycle failure**	**Queue spillback**	**Obstruction**	**Crossing stripes**	**Stop bar violation**	**Presence of bus stop**	**Absence of bike lanes**	**Overall assessment**
S1	Stadium Rd. @ Gale Lemerand Dr.	N	Y	Y	N	N	N	N	Y	N	N	3
S2	W Univ. Ave. @ 20th Tr. (Gale Lemerand Dr.)	N	N	N	Y	N	Y	N	N	Y	Y	4
S3	W Univ. Ave. @ 18th St.	N	Y	Y	N	N	N	N	N	Y	Y	4
S4	W Univ. Ave. @ 17th St.	N	N	N	N	N	N	N	N	N	Y	1
S5	W Univ. Ave. @ 15th St.	N	N	N	N	N	N	N	N	Y	Y	2
S6	W Univ. Ave. @ 13th St.	N	N	N	N	N	Y	N	N	N	Y	2
S7	SW 2nd Ave. @ 13th St.	N	N	N	Y	N	N	Y	N	Y	Y	4
S8	SW 4th Ave. @ 13th St.	N	N	N	N	N	N	N	Y	N	Y	2
S9	SW 5th Ave. @ 13th St.	N	N	N	Y	Y	N	Y	N	Y	Y	5
S10	SW 8th Ave. @ 13th St.	N	N	N	N	N	Y	N	N	Y	Y	3
S11	Museum Rd. @ Newell Dr.	N	Y	N	N	N	N	N	N	N	N	1
S12	Museum Rd. @ Center Dr.	N	Y	Y	N	N	N	N	N	Y	N	3
S13	Museum Rd. @ Gale Lemerand Dr.	N	N	N	N	N	N	N	N	N	N	0

The main observations resulting from the field visit are as follows:

- All the intersections have pedestrian pushbuttons.
- Frequent jaywalking was observed, particularly around some of the intersections (S1, S3, S11 and S12).
- A significant number of pedestrians do not follow signal indications when crossing at the signalized intersection crosswalks.
- Some of the intersections (S2, S7 and S9) experienced cycle failures during the observation time.
- Queue spillback was observed at the intersection S9 in the southbound direction.
- Right-turning vehicles waiting to turn at intersection S7 may block the pedestrians' view of the pedestrian walk/don't walk signal.
- At the intersection S6 (W University Ave & 13th St) there is a building in the NW corner that may obstruct pedestrians' (as well as skateboarders & bicyclists') view of southbound vehicles.
- Some of the intersections do not have painted crossing stripes in the pedestrian crosswalks.
- Trees may block vehicles' view of pedestrians at intersections S9 & S10.

3.1.2 Mid-block Crossings

A total of eleven (11) mid-block crossings were identified along the arterials of the study network (C6 is the only unsignalized intersection in this group). There are seven mid-block crossings along the Gale Lemerand Drive and the remaining four are located along Museum Rd. These roadways generally have lower speeds (the speed limit on campus is 20 mph.) The volume of pedestrians in these mid-block crossings is high during several times each day and particularly between class periods.

The observers took photos of all the mid-block crossings within the study area. Pictures of C6 are shown in Figure 3. Pictures of each mid-block crossing along with the preliminary observations regarding mid-block crossings within the study area are provided in Appendix B.

Figure 3 Photos of Museum Rd. and Reitz Union Dr. (C6)

Several operational features were collected for each of the mid-block crossings and their quality was assessed qualitatively based on these features (Table 2). The first and second column of the table provide the ID and the location of the mid-block crossings. The remaining features are as follows:

- **Number of Warning Signs**: The number of warning signs around the mid-block crossing (both sides of the road).
- **Types of Warning Signs:** There are three types of warning signs provided around the mid-block crossings: yellow diamond, rectangular, and yellow diamond with flashing beacon
- **Distance of Warning Signs:** This column reports the furthest distance of warning signs along the roadway from mid-block crossings. Some warning signs are located within 10 ft. from the crossings whereas some are more than 25 ft. from the crossings.
- **Presence of Median:** Presence of a traffic separator or divider.
- **Presence of Bus Stop:** "Y" indicates there is at least one bus stop within about 100 ft from the stop bar of any approach.
- **Obstructions**: This column indicates whether there are obstructions such as large trees, buildings that may block the vehicle's view of pedestrians/bicyclists.
- **Overall Assessment:** The overall quality of the crossing was assessed for each of locations based on the information in the previous columns. Scores of 0 or 1 are assigned to each column with "Y/N" type of entries. A scaling system (described in Appendix B) is used for the remaining characteristics. These numbers are added up to assess each mid-block crossings (last column of Table 2).

In summary, the following are concluded regarding mid-block crossing operations within this network:

- Only two mid-block crossings (C5 & C9) have flashing beacons with warning signs.
- There is no uniformity in warning signage across the network.
- Two mid-block crossings (C1 & C4) have trees around which may block the vehicles' view of pedestrians.
- Buses stopped at bus stops near the mid-block crossings may block the view of warning signs for the approaching drivers.

Table 2 Summary of qualitative observations for the mid-block crossings

ID	Between Signals	# of warning signage	Type of warning sign	Distance of signs from crossing (ft)	Presence of median	Bus stop near mid-block crossing	Obstructions	Overall Assessment
C1	S1 & S2	5	Yellow diamond	>25	Y	N	Trees	3.5
C2	S1 & S2	4	Rectangular, yellow diamond	<10	N	N	N/A	2.5
C3	S1 & S2	2	Yellow diamond	<10	N	N	N/A	4
C4	S1 & S2	2	Yellow diamond	>25	N	Y	Large tree (SB)	3
C5	S10 & S11	4	Rectangular, yellow diamond, and flashing	>25	Y	Y	N/A	0
C6	S12 & S13	3	Rectangular and yellow diamond	>25	N	N	Corner building	3.5
C7	West of S13 along Museum Rd.	2	Yellow diamond	<10	N	N	Road Crest (EB)	5
C8	West of S13 along Museum Rd.	2	Yellow diamond	<10	N	Y	Road Crest (WB)	4
C9	S13 & S1	5	Rectangular, yellow diamond, and flashing	>25	Y	Y	Road Curvature (Horizontal)	1
C10	S13 & S1	3	Yellow diamond	<10	N	N	Road Curvature (Horizontal)	4.5
C11	S13 & S1	3	Yellow diamond	<10	N	Y	N/A	2.5

3.2 Crash Data Analysis

In this section, we conduct safety analysis by using historical crash data. Pedestrian and bicyclist crashes are analyzed intersection by intersection, by day of the week, and time of the day.

3.2.1 Data Collection

The research team obtained crash data from May 2014 to May 2019 from the Signal Four Analytics database, which is an inventory of crash reports filled by police officers. The data in this database include person type (driver, occupant, pedestrian, etc.), number and severity of injuries, violation of traffic law, time of day, day of week, alcohol/ drug impairment, latitude and longitude of the crash location, vehicle characteristics, event characteristics (manner of the collision, number of vehicles involved, direction of travel), and environment (weather conditions). The crash reports along with their GIS-based crash location data were downloaded for the entire network using appropriate extraction tools available in Signal Four Analytics. Data were also obtained for up to 250 feet along cross streets intersecting the urban streets of interest. The researchers also downloaded the crash narratives associated with each of the crashes in the corridor, and reviewed them to obtain additional information about the crashes. Appendix C presents summary descriptions for each of the pedestrian and bicycle crashes in this corridor including information gleaned from the narratives.

A total of 1110 vehicle crashes, 49 pedestrian crashes and 48 bicycle crashes were recorded within the study area between May 2014 and May 2019 (Table 3).

Table 3 Summary of crashes within the study network (May 2014 and May 2019)

Crash Type	Total Crashes	Fatal	Incapacitating	Others
Vehicle	1110	0	11	1099
Pedestrian	49	0	11	38
Bicycle	48	1	3	44

Figure 4 shows the distribution of pedestrian, bicycle and vehicle crashes by signalized intersection (traffic signal icon), mid-block crossing (pedestrian walking icon), and other locations such as unsignalized intersections (red icon) within the study network. For example, at the top-left corner of the figure, for the intersection of W Univ. Ave. and Gale Lemerand Dr., we indicate "4/4/48", i.e., 4 pedestrian, 4 bicyclist, and 48 vehicle (only) crashes were observed during our analysis period.

The three intersections with the most frequent pedestrian crashes are along West University Avenue with the intersection of Buckman Drive, with University Avenue having the highest number of crashes. The intersection at the W Univ. Ave. and SW 13th St. has the highest number of bicycle crashes. The top three intersections in terms of total vehicle crashes are all along 13th Street.

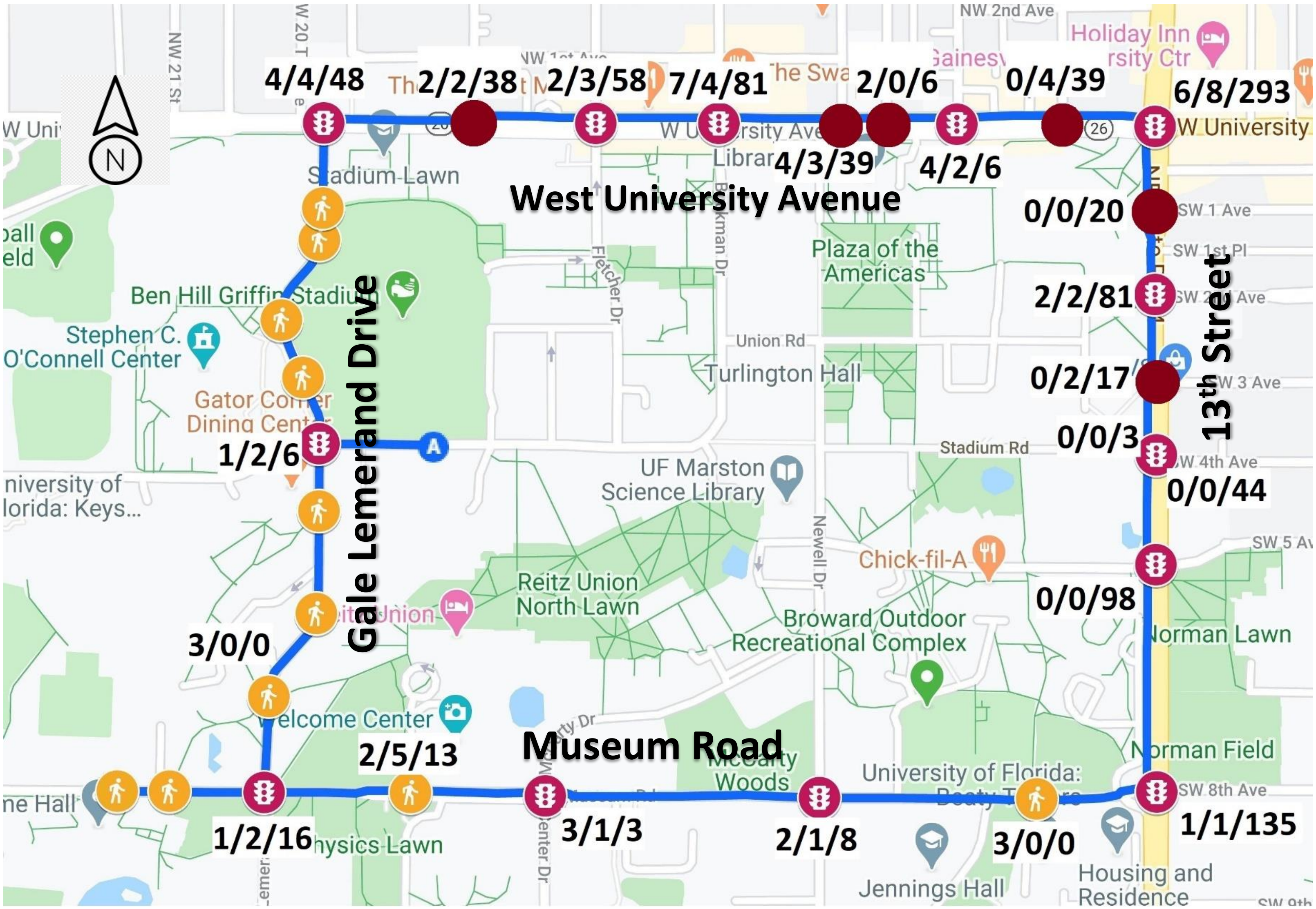


Figure 4 Number of pedestrian, bicyclist and vehicle (only) crashes by location on the study network (format: ped/bike/vehicle)

3.2.2 Pedestrian Crashes

Table 4 shows the distribution of pedestrian crashes by year. The table indicates a decline in the number of pedestrian crashes from May 2014 to May 2019. There are approximately 220-240 vehicle crashes per year in this same network (yielding the 1110 total vehicle crashes as indicated in Table 4).

Table 4 Pedestrian crashes by year

Year	Gale Lemerand Drive	West University Avenue	13th Street	Museum Road	Total Crashes
May 2014-Dec 2014	1	5	2	1	9
2015	3	6	1	2	12
2016	2	5	3	1	11
2017	1	1	1	4	7
2018	1	1	0	3	5
Jan 2019-May 2019	0	3	0	0	3

Table 5 shows the distribution of pedestrian crashes by day of the week. As shown, Tuesdays and Fridays generally have a higher numbers of crashes. Fridays also have the highest number of crashes (total vehicle crashes) of any day of the week.

Table 5 Pedestrian crashes by day of the week

Day of the Week	Gale Lemerand Drive	West University Avenue	13th Street	Museum Road	Total Crashes
Sunday	0	3	1	0	4
Monday	0	2	1	1	4
Tuesday	5	2	2	1	10
Wednesday	1	3	1	3	8
Thursday	0	3	0	0	3
Friday	1	6	0	4	11
Saturday	2	2	2	2	8

Table 6 shows pedestrian crashes by month of the year. October has the highest number of pedestrian crashes (three of the ten pedestrian crashes in October occurred during football game days). Pedestrian crashes are fewer during the summer months, consistent with reduced student presence on campus. These month-of-the year trends are also generally consistent with those for total vehicle crashes. August, October, and September are the top three months in terms of total vehicle crashes in the network.

Table 6 Pedestrian crashes by month of the year

Month of the year	Gale Lemerand Drive	West University Avenue	13^{th} Street	Museum Road	Total Crashes
January	0	1	0	1	2
February	1	2	1	2	6
March	0	2	0	0	2
April	1	1	0	0	2
May	0	1	0	1	2
June	1	0	0	0	1
July	0	2	2	0	4
August	1	2	0	2	5
September	1	2	1	1	5
October	2	4	2	2	10
November	2	2	1	0	5
December	0	2	0	2	4

Table 7 shows the time of the day distribution of pedestrian crashes. The late night period from 11 PM – midnight has a higher incidence of pedestrian crashes, especially along the West University Avenue corridor which has several restaurants. In contrast, total vehicle crashes are the highest during the PM peak (4-5 PM) for this network. The vast majority of vehicle crashes occur Noon – 6 PM with relatively fewer crashes during the morning period.

Table 8 presents the distribution of pedestrian crashes by contributing factors (the %s do not sum to 100% as there could be multiple factors for a crash). Inattention of the driver was more likely to be a cause than the inattention of the pedestrian. Alcohol was a factor in about 10.6% of the crashes, with pedestrians more likely to be intoxicated. This is consistent with the increase in the number of pedestrian crashes during football games. In 27.7% of the cases, the vehicle failed to yield for the pedestrian. In 23.4% of the crashes, the pedestrian ran in front of the vehicle.

Table 7 Pedestrian crashes by time of day

Time of the Day	Gale Lemerand Drive	West University Avenue	13^{th} Street	Museum Road	Total Crashes
12:00 AM	1	0	1	1	3
1:00 AM	0	4	1	0	5
2:00 AM	0	1	1	0	2
3:00 AM	0	1	0	0	1
4:00 AM	0	0	0	0	0
5:00 AM	0	0	0	0	0
6:00 AM	0	0	0	0	0
7:00 AM	0	0	0	0	0
8:00 AM	0	0	0	1	1
9:00 AM	0	2	0	1	3
10:00 AM	1	1	0	0	2
11:00 AM	0	1	0	1	2
12:00 PM	1	0	0	0	1
1:00 PM	1	0	0	0	1
2:00 PM	0	0	0	2	2
3:00 PM	0	1	1	0	2
4:00 PM	0	0	1	1	2
5:00 PM	0	1	0	1	2
6:00 PM	0	0	0	0	0
7:00 PM	0	0	0	1	1
8:00 PM	1	2	0	1	4
9:00 PM	1	1	0	0	2
10:00 PM	1	1	1	1	4
11:00 PM	2	5	1	0	8

Table 8 Distribution of pedestrian crashes by crash contributing factor

Crash Contributing Factor	% Crashes
Inattention: Vehicle Driver	25.5 %
Inattention: Pedestrian	12.8 %
Speeding	2.1 %
Alcohol Driver	2.1 %
Alcohol Pedestrian	8.5 %
Failed to see Pedestrian	14.9 %
Failed to yield for Pedestrian	27.7 %
Failed to yield for Vehicle	10.6 %
Pedestrian Ran in front of vehicle	23.4 %
Other Crashes (Driver in Stress/Driver Aggressive Behavior/Glare on windshield/Poor lights-dark)	12.8 %

Based on other crash characteristics, we also observe the following:

- In 52.5% of the crashes, the driver was at fault, and in 45.76% of the crashes the pedestrian was at fault. Only in 1.7% of the crashes none was at fault.
- Approximately 66.7% of the pedestrian crashes occurred within the crosswalk of signalized intersections while 22% were “non-crosswalk” crashes. There are two pedestrian signalized mid-block crossings along Gale Lemerand Drive and Museum Road. Approximately 11.1% of the pedestrian crashes occurred at the mid-block crossings of the study area.
- In 66% of the pedestrian crashes, the striking vehicle was traveling through the intersection, while in 31.9% of the pedestrian crashes the striking vehicle was turning left.
- Approximately 49% of the total pedestrian crashes occurred when the vehicle had the right-of-way. In these types of crashes, pedestrians failed to yield for vehicles and/or ran a red “do-not-walk” sign. Of the pedestrian crashes, 8.6% occurred when there was a red signal for the vehicle, and 11.4% occurred when the pedestrian failed to yield to a vehicle at a red “do-not-walk” sign. In 31.4% of the crashes there was no traffic control device in the vicinity.

3.2.3 Bicycle Crashes

Table 9 shows the distribution of bicycle crashes by year. The number of crashes have been fluctuating over the last five years. As indicated earlier, there are 220-240 vehicle crashes per year in this same corridor.

Table 9 Bicycle crashes by year

Year	Gale Lemerand Drive	West University Avenue	13^{th} Street	Museum Road	Total Crashes
May 2014- Dec 2014	2	5	1	1	9
2015	5	2	4	3	14
2016	0	3	2	1	6
2017	4	4	4	2	14
2018	2	4	2	1	9
Jan 2019- May 2019	0	0	4	1	5

Table 10 shows the distribution of bicycle crashes by day of the week. The bicycle crashes are higher on Wednesdays followed by Tuesdays. This may be due to higher bicycle activity during the weekday then during weekends. In contrast, Fridays have the highest number of vehicle crashes of any day of the week.

Table 10 Bicycle crashes by day of the week

Day of the Week	Gale Lemerand Drive	West University Avenue	13^{th} Street	Museum Road	Total Crashes
Sun	0	2	0	0	2
Monday	1	4	2	1	8
Tuesday	2	3	3	2	10
Wednesday	2	2	4	2	10
Thursday	2	3	2	2	9
Friday	0	4	3	0	7
Saturday	2	0	0	2	4

Table 11 shows the distribution of bicycle crashes by month of the year. Bicycle crashes are slightly higher during the fall and spring semesters and lower during the summer and winter breaks, as expected. These month-of-the year trends are also generally consistent with those for total vehicle crashes. August, September and October are the top three months in terms of total vehicle crashes in this corridor.

Table 11 Bicycle crashes by month of the year

Month of the year	Gale Lemerand Drive	West University Avenue	13^{th} Street	Museum Road	Total Crashes
January	0	0	1	0	1
February	2	0	1	2	5
March	1	0	2	1	4
April	1	4	1	0	6
May	2	1	1	0	4
June	2	0	2	0	4
July	0	1	0	1	2
August	0	3	1	0	4
September	1	2	2	2	7
October	2	2	2	1	7
November	2	1	0	2	5
December	0	4	1	0	5

Table 12 shows the number of crashes by hour of the day. There are more crashes in the afternoon between 1 pm and 6 pm. The majority of vehicle crashes also occur Noon – 6 PM with relatively fewer crashes during the morning period.

Table 12 Bicycle crashes by hour of the day

Time of the Day	Gale Lemerand Drive	West University Avenue	13th Street	Museum Road	Total Crashes
12:00 AM	0	0	0	0	0
1:00 AM	1	0	0	0	1
2:00 AM	0	1	0	0	1
3:00 AM	0	0	0	0	0
4:00 AM	0	0	0	0	0
5:00 AM	0	0	0	0	0
6:00 AM	0	0	0	0	0
7:00 AM	0	0	2	1	3
8:00 AM	4	0	1	0	5
9:00 AM	0	2	0	1	3
10:00 AM	0	0	1	1	2
11:00 AM	0	1	0	0	1
12:00 PM	0	1	1	3	5
1:00 PM	2	0	1	1	4
2:00 PM	1	3	2	0	6
3:00 PM	1	2	0	1	4
4:00 PM	1	0	1	0	2
5:00 PM	2	1	1	0	4
6:00 PM	0	3	1	1	5
7:00 PM	1	3	0	0	4
8:00 PM	0	1	1	0	2
9:00 PM	0	0	1	0	1
10:00 PM	0	0	0	0	0
11:00 PM	0	0	1	0	1

Table 13 Bicycle crashes by traffic control device

S. No	Crashes by Traffic Control Device	% Crashes
1	No Traffic Control	29.6
2	Green Traffic Light for Vehicle	15.9
3	Red Traffic Light for Vehicle	15.9
4	Red walk Sign for Pedestrian	9.1
5	Stop Sign	25.00
6	Green walk sign	4.6

Table 14 shows the distribution of bicycle crashes by contributing factor. In 25% of the cases, the driver failed to see the bicyclist. Approximately 33.3% of the crashes were a result of either the driver or the bicyclist failing to yield. In 20.8% of the crashes, bicyclists traveled in front of the vehicle.

Table 14 Bicycle crashes by crash contributing factor

Crash Contributing Factor	**% Crashes**
Inattention Bicyclist	4 %
Inattention Vehicle Driver	19 %
Confusion Vehicle Driver	4 %
Alcohol/ Drug Vehicle Driver	0 %
Alcohol/ Drug Bicyclist	2 %
Failed to see Bicyclist	19 %
Failed to yield for Bicyclist	15 %
Failed to yield for Vehicle	8 %
Bicyclist Ran in front of vehicle	6 %
Ran red walk sign	2 %
Blind Spot for Bus	2 %
View obstructed for Bicyclist	4 %
Other Crashes (Bicycle in Travel Lane, other vehicle)	15 %

Based on our review of additional crash attributes and crash narratives, we observe the following:

- In 62.5% of the crashes the vehicle driver was at fault and in 25% of the crashes the bicyclist was at fault. In some cases, the vehicle stopped in the travel lane, and the passenger opened the door hitting the passing bicyclist. These crashes made up 2.1% of the bicycle crashes. In 10.4% of the total bicycle crashes, no one was at fault (based on the judgement of the police officer writing up the crash report).
- 81.3% of the crashes occurred at the crosswalk of the intersection. Only 2.1% of the bicyclist crashes occurred in the travel lane (in these cases the bicyclist was struck by a vehicle driving in parallel to the cyclist).
- 50% of the bicycle crashes occurred when the striking vehicle was turning right. In 16.7% of the total bicycle crashes the striking vehicle was turning left, and 25.9% of crashes occurred when the striking vehicle was traveling through the intersection. 7.4% of the crashes occurred while the car was stopped. In those cases the bicyclist lost control and hit the vehicle.

3.3 Traffic Operational Analysis

Data were collected at three signalized intersections and one unsignalized intersection with pedestrian crosswalks to perform highway capacity analysis and evaluate operational performance. The signalized intersections selected for analysis are located along West University Avenue, which has the highest number of crashes (pedestrian and bicyclist) within the study network. Fridays between 2pm to 4pm is the most critical time for crashes and therefore it was selected as the analysis period. The signalized intersections analyzed are: W Univ. Ave. & 13th St. (S6), W Univ. Ave. & 17th St. (S4), and W Univ. Ave. & Gale Lemerand Dr. (S2). There is generally much higher traffic along W Univ. Ave. & 13th St. compared to other signalized intersections in the network.

The unsignalized intersection with pedestrian crosswalks selected for the analysis (Museum Rd. & Reitz Union Dr., which is practically a two-way stop- controlled (TWSC) T-intersection with a pedestrian mid-block crossing) has the highest number of pedestrian and bicycle crashes. The selected signalized intersections and mid-block crossing are marked in circles as shown in

Figure 5.

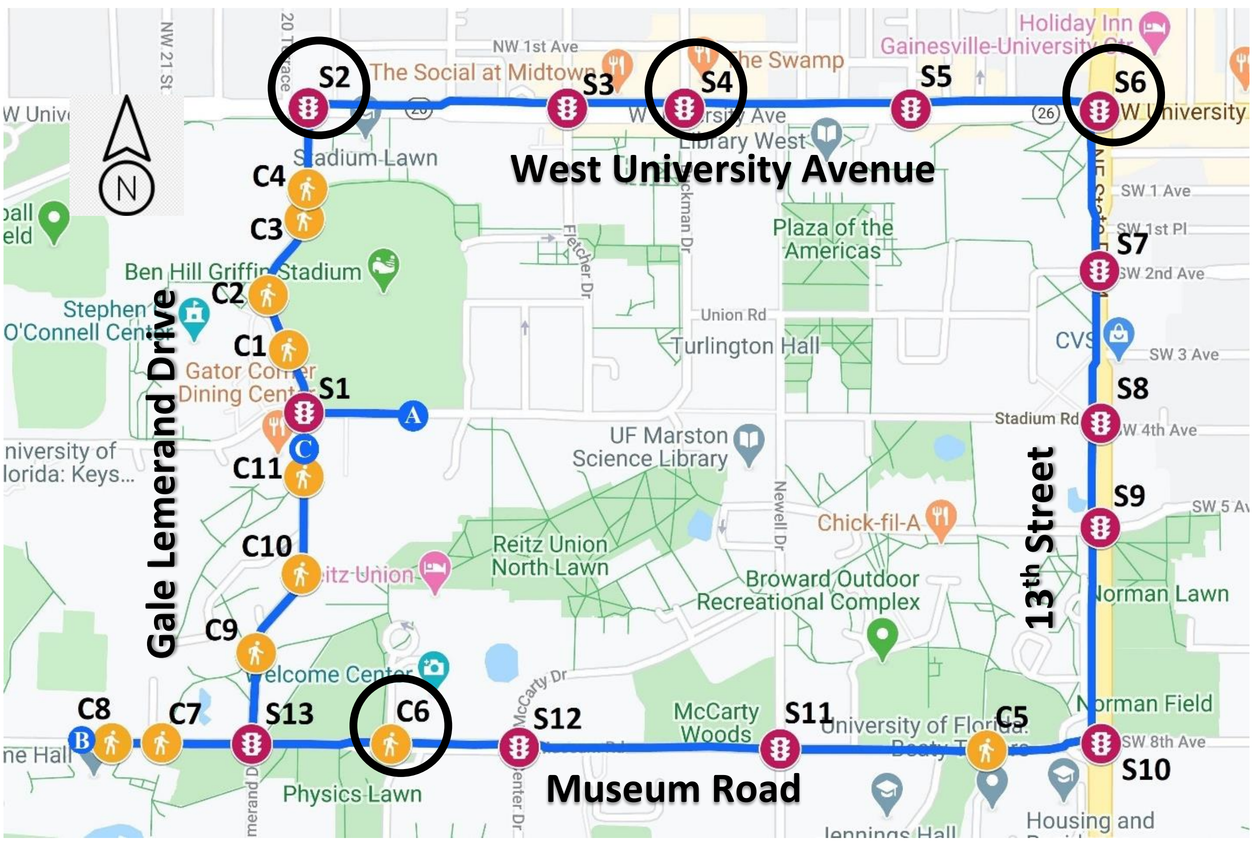


Figure 5 Traffic analysis locations shown in black circles

Data collection at Museum Rd. & Reitz Union Dr. (C6) was carried out in November 2019. However, the data at the signalized intersections were collected after the COVID pandemic started, as the research team was waiting for the purchasing and installation of the fisheye cameras. Therefore, the volumes at these intersections are significantly lower than typical. We plan to collect additional field data once the campus and the surrounding network return to higher volumes. The data collection dates for each of the study locations are shown in Table 15.

Table 15 Data collection date of selected intersections and crossing

Signal	**Data collection date**
W Univ. Ave. & 13th St. (S6)	13-Mar-20
W Univ. Ave. & 17th St. (S4)	24-Apr-20
W Univ. Ave. & Gale Lemerand Dr. (S2)	13-Mar-20

Data were collected based on the Highway Capacity Manual[1] (HCM, 6^{th} Edition) procedures (Chapter 19 "Signalized Intersections" and Chapter 20 "TWSC intersections"). Recorded video data from both fisheye and Bosch dome cameras were used to gather the required data for the signalized intersection analysis. According to the HCM, the pedestrian level of service (LOS) along mid-block crossings can be evaluated using the Chapter 20 (TWSC intersections) procedures. Field observations were made to collect the data at the unsignalized intersection with pedestrian crosswalks.

3.3.1 Signalized Intersections

Data were collected at three signalized intersections. Additional data may be collected later as needed for the purposes of this project when the traffic volumes are higher.

Geometric Data

The required data for highway capacity analysis include geometric design data, signal timing data, and traffic flow and characteristics. Geometric data were obtained using the aerial view from Google Maps (Table 16).

The intersection of W Univ. Ave. & 13^{th} St. (S6) has four approaches (Figure 6). The northbound, southbound and westbound approaches have 3 lanes and a left turn bay of 310 ft, 470 ft and 240 ft respectively. All these approaches have an exclusive through lane and a shared through and right turn lane. The eastbound approach has 4 lanes including a nearly 450 ft left-turn bay, two exclusive through lanes and a dedicated right turn bay of approximately 240 ft. There is no on-street parking along any of the approaches. The approach grade is assumed to be 0% for all approaches. The geometric design information for the three intersections are presented in Appendix D (Tables D1, D6, D12).

[1] Highway Capacity Manual (2016). A Guide for Multimodal Mobility Analysis. Transportation Research Board, Washington, DC.

Table 16 Geometric design information for W Univ. Ave. & 13th St.

Geometric Data	EB			WB			NB			SB		
	L	Th	R	L	Th	R	L	Th	R	L	Th	R
Number of lanes	4			3			3			3		
Average lane width (ft)	11			11			11			11		
Number of receiving lanes (ln)	2			2			2			2		
Turn bay length (ft)	450	690	240	240	605	-	310	545	-	470	590	-
Presence of on-street parking	0			0			0			0		
Approach grade (%)	0			0			0			0		
Total walkway width (ft)	10			10			10			10		
Crosswalk width (ft)	10			10			10			10		
Crosswalk length (ft)	70			70			75			70		
Corner radius (ft)	30			30			35			20		

Figure 6 Layout and lane configuration of W Univ. Ave. & 13th St.

Traffic Data

Fisheye cameras are ultra-wide-angle panoramic IP camera that provide a warped 3D view of the intersection. Videos from these cameras were recorded using the CoG ATMS. A fisheye view of the signalized intersection at W Univ. Ave. & 13th St. is shown in Figure 7. Bosch cameras previously installed by the CoG were also used to obtain videos from different perspectives. These are dome type cameras (AutoDome 800 HD) and can capture 1080p video at 30 frames per second with 240x zooming capability. These cameras can be rotated to capture a 360° view around their installation spot.

A total of sixty minutes of video were recorded for W Univ. Ave. & 17th St. (S4) and 45 minutes of video for the intersections of W Univ. Ave. & 13th St. (S6) and W Univ. Ave. & Gale Lemerand Dr. (S2). These were recorded on Fridays between 2 pm and 4 pm, as indicated previously. The analysis period was 15 minutes, as prescribed in the HCM. The recorded videos were used to obtain the traffic volumes at each intersection.

Table 17 summarizes the traffic throughput and characteristics data obtained for W Univ. Ave. and 13th St. intersection during the first period of analysis. The complete input data tables and the analysis results for all three signalized intersections are provided in Appendix D (Tables D2 to D4, D7 to D10 and D13 to D15).

Generally, all approaches of the W Univ. Ave. & 13th St. intersection carry high volumes during the analysis period. Right turns on red are not allowed for any of the approaches of the intersection. A high number of pedestrians use the intersection crosswalks to cross along the north cross walk, resulting in long queues for the westbound right-turning vehicles.

Figure 7 Fisheye camera view of W Univ. Ave. & 13th St.

Table 17 Traffic Flow and Characteristics at W Univ. Ave. & 13th St.

Traffic Characteristics	**EB**			**WB**			**NB**			**SB**		
	L	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	160	356	220	92	340	80	264	610	198	76	616	108
RTOR flow rate (veh/h)	0			0			0			0		
Percentage heavy vehicles	5%	4%	5%	4%	5%	9%	2%	4%	7%	0%	5%	8%
Platoon ratio	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Upstream filtering adjustment factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Initial queue (veh)	4	5	3	9	15	15	6	6	6	7	11	11
Pedestrian flow rate (ped/h)	104			204			76			212		
Bicycle flow rate (bicycles/h)	0			0			0			0		
On-Street parking maneuver rate (veh/h)	0			0			0			0		
Local bus stopping rate (buses/h)	0			0			0			0		
Midsegment 85th percentile speed (mi/h)	30			30			30			30		
Number of right-turn islands	0			0			0			0		

Signal Timing Data

Signal timing data were obtained from the City of Gainesville (CoG) Advanced Traffic Management System (ATMS) database. The signal timing data of W Univ. Ave. & 13th St. are shown in Table 18. The signal timings for the study signalized intersections are provided in Appendix D (Table D5, D11 & D16).

Table 18 Signal timing data for W Univ. Ave. & 13th St.

Phase Information	**EBL**	**EBT**	**WBL**	**WBT**	**NBL**	**NBT**	**SBL**	**SBT**
Maximum Green (Gmax) or Phase Split, s	25	45	25	45	30	70	25	55
Yellow Change Interval (Y), s	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.8
Red Clearance Interval (Rc), s	2	2	2	2	2	2	2	2
Minimum Green (Gmin), s	7	12	7	12	7	12	7	12
Start-Up Lost Time (lt), s	2	2	2	2	2	2	2	2
Extension of Effective Green (e), s	2	2	2	2	2	2	2	2
Passage (PT), s	3	3.5	3	3.5	3	3.5	2.5	3.5
Recall Mode	Off	Off	Off	Off	Off	Off	Off	Off
Dual Entry	No	Yes	No	Yes	No	Yes	No	Yes
Walk (Walk), s		7		7		7		7
Pedestrian Clearance Time (PC), s		24		22		22		23

Analysis Results

The operational analysis for the signalized intersections was conducted using the HCS software. Analysis results are presented providing both vehicular LOS and pedestrian LOS. Bicycle LOS was not estimated since the signalized intersections studied have no bike lanes. The analysis results are presented in Table 19. As shown, the vehicular LOS for the intersection of W Univ. Ave. & 13th St. is estimated to be D, with an average control delay of 51 seconds per vehicle. Given the data were obtained after the COVID pandemic, the LOS is higher than typical. The LOS of the other two intersections is B. The pedestrian LOS for the crosswalks of W Univ. Ave. & 13th St. is C, whereas pedestrian LOS is found to be B for the other intersections. The detailed HCS analysis and results are provided in Appendix D.

Table 19 HCM analysis results for the three signalized intersections

Signal	**Motorized vehicle LOS**		**Ped LOS**
	Control delay (s/veh)	**LOS**	
W Univ. Ave. & 13th St (S6)	50.63	D	C
W Univ. Ave. & 17th St (S4)	13.70	B	B
W Univ. Ave. & Gale Lemerand Dr. (S2)	12.25	B	B

3.3.2 Unsignalized Intersection

The layout and lane configuration of the unsignalized intersection at Museum Rd. & Reitz Union Dr. are shown in Figure 8)

Geometric Design Data

The unsignalized intersection consists of three approaches with two lanes per approach. There are bike lanes along the east-west approaches. It has three legs with three crosswalks. The width of the crosswalks along the east and west approaches is approximately 12 ft., while the north crosswalk has a width of 13 ft. There is no raised median for any of the crosswalks.

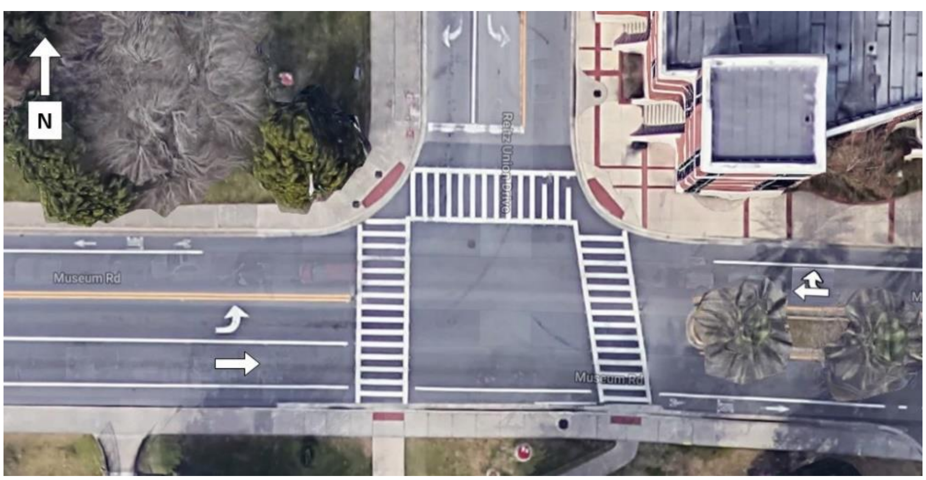


Figure 8 Layout and lane configuration of Museum Rd. & Reitz Union Dr. (C6)

Traffic Data

The field data collection took place on Friday, November 8, 2019, between 3:00 pm to 4:00 pm. Table 20 shows the field data collected at this location. The procedures consisted of measuring pedestrian LOS and obtaining traffic counts for vehicles, pedestrians, and bicyclists. Five observers were physically present at this location to collect the necessary data.

The vehicular flow along the east-west direction is higher than that of the southbound, which consists of traffic from the Reitz Union parking garage. The average pedestrian walking speed was estimated by recording pedestrians' average crossing time for each crosswalk. When a group of pedestrians or more than one pedestrian were observed crossing, this was logged as a pedestrian platoon. Pedestrian platooning was present along all approaches at this location.

Driver's yielding opportunities and the number of yielding drivers were counted to observe the driver yielding behavior at the crosswalks. An approaching driver was considered to have an "opportunity to yield" if the driver was a minimum distance away when a pedestrian arrives at the curb. The minimum distance used was equivalent to the stopping sight distance, which is approximately 112 ft. for vehicle speeds of 20 mph (based on 2.5 s of driver reaction time and a conservative deceleration rate of 11.2 feet per sec). The number of drivers that yielded was obtained based on whether a driver with a yielding opportunity yields the right of way to the pedestrian.

Table 20 Data collected at Museum Rd. & Reitz Union Dr.

Approach	**Eastbound**	**Westbound**	**Southbound**
Number of lanes	2	2	2
Presence of a raised median (Y/N)	N	N	N
Posted speed limit (mi/h)	20	20	20
Presence of pedestrian platooning (Y/N)	Y	Y	Y
Vehicular flow rate (veh/h)	441	414	209
Average pedestrian walking speed (ft/s)	4	4	4
Pedestrian start-up time and end clearance time (s)	3	3	3
Crosswalk length	46	44	12
Crosswalk width	12	12	13
Pedestrian Count			
Pedestrian volume	151	191	128
Driver's yielding opportunities	153	88	N/A
Number of drivers yielded	120	82	N/A
Vehicle Count			
Left	298	414	81
Through/Right	143	123	128
Bicycle Count	20	38	N/A

The pedestrian LOS was measured using the HCM methodology for unsignalized intersections using the traffic and pedestrian counts collected in the field. Drivers' yield rates for the east and west legs of the unsignalized intersection were also calculated from driver's yielding opportunities and the number of drivers that yielded. The resulting pedestrian LOS are shown in Table 21.

Table 21 Pedestrian LOS at Museum Rd. & Reitz Union Dr.

	Eastbound (West leg)	**Westbound (East leg)**	**Southbound (North leg)**
Flow (ped/hr)	151	191	128
Two-Stage crossing	No	No	No
Pedestrian platooning	Yes	Yes	Yes
Conflicting vehicular flow (veh/h)	900	739	-
Yield rate	78.4%	93.2%	N/A
Average pedestrian delay (s)	14.6	5.9	2.7
Level of service (LOS)	C	B	A

3.4 Travel Time and Speed

Travel time and speed data along several corridors in Gainesville are available through the BlueARGUS dataset operated by TrafficCast International, Inc. This dataset contains data for one of the four corridors (West University Ave between Gale Lemerand Drive and 13th Street) in the study area. Both travel time and speed data were obtained for two periods of two weeks each, to reflect pre-COVID and post-COVID traffic patterns:

- Period A (pre-COVID) - Jan 25 to Feb 09, 2020
- Period B (post-COVID) - Mar 21 to Apr 05, 2020

Several plots are provided (Figure 9 to Figure 16)to illustrate these trends. The graphs show average speeds and travel times in the given peak period for the given day.

West University Avenue

Figure 9 and 10 show speed and Figure 10,11 show travel time along W Univ. Ave. For both the WB and EB directions speeds increased in period B (when the University moved classes online and the city announced COVID-related measures) compared to period A (when city and university were operating normally). Please note one data point (travel time of 290s) on Figure 11a is off the chart due to a traffic incident.

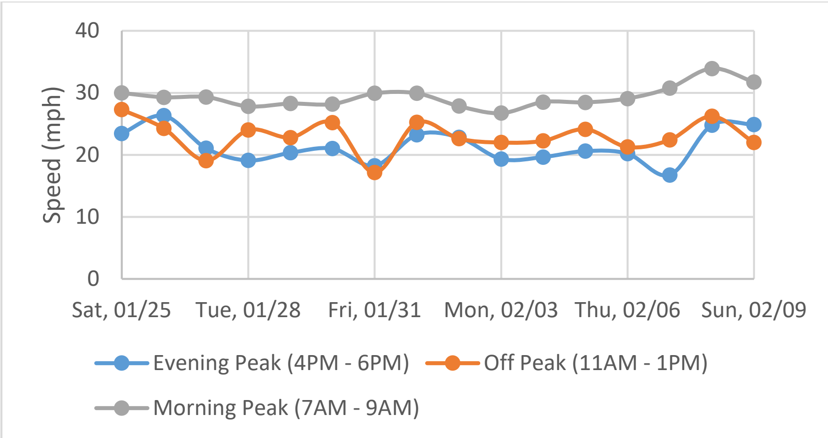
The highest speeds are observed in the AM peak for both directions (for both pre- and post-COVID periods). Most of the pedestrian crashes occur during this time. However, most of the bicycle-related crashes occur during Friday afternoon and evenings when the traffic moves at the slowest pace compared to any other time during the week. This can be due to a high number of vehicles and bicycles, as faculty, staff and students depart from UF at the end of the workweek.

13th Street

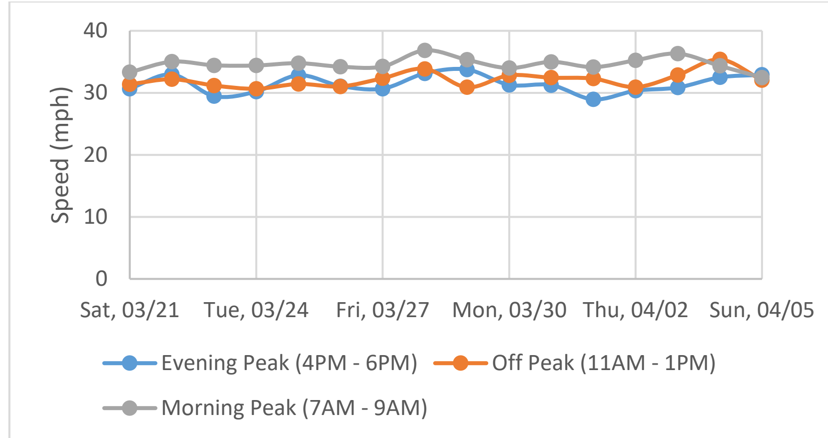
Figure 13 and 14 show speed and Figure 15,16 show travel time show travel time along 13th St. Due to lack of Bluetooth travel time stations matching the exact coordinates of the 13th St. section along the corridor, we used the section from SW 23rd Dr. /Archer Rd. to Univ. Ave. /13th St. For both the NB and SB directions, speeds increased in period B (when the University moved classes online and the city announced COVID related measures) compared to period A (when city and university were operating normally).

The W Univ. Ave. and 13th St. arterials have the same speed limit (30 mph). However, speeds on W Univ. Ave. are higher than those on 13th St (20 - 35 mph compared to 15 - 25 mph). This correlates with the occurrence of pedestrian crashes. W Univ. Ave. has much higher pedestrian crash rates than 13th St. (Table 4). In addition, a number of nighttime crashes occurred with pedestrians on W Univ. Ave. when the vehicular speeds are high.

Although pedestrian crashes are low at 13th St. compared to W. Univ. Ave., bicycle crashes are high. Most of the bicycle crashes occur during the AM and Off-peak periods on Tuesdays and Wednesdays when the vehicular speeds are relatively high on 13th St., especially in the SB direction. These are the time intervals when most of the university classes take place. Students are often required to cross from one side of the 13th St. to another. Though there is a tunnel at the Inner Rd. intersection, bicyclists may prefer to cross 13th St. above ground due to over-crowding of the tunnel.

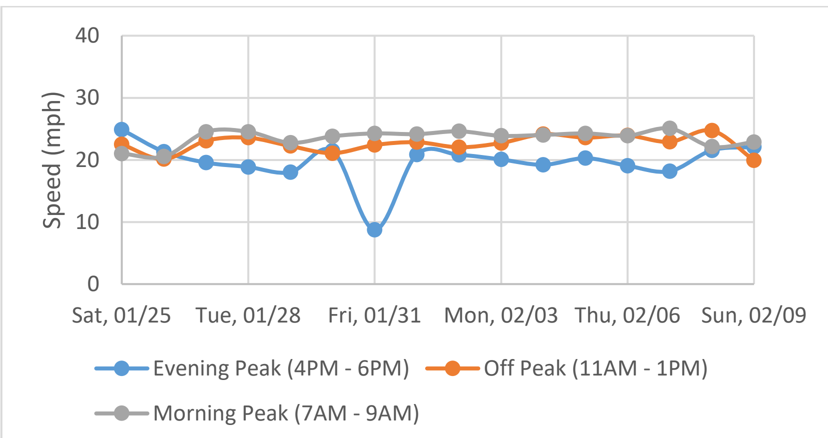


(a) Jan 25- Feb 09, 2020 (Period A)

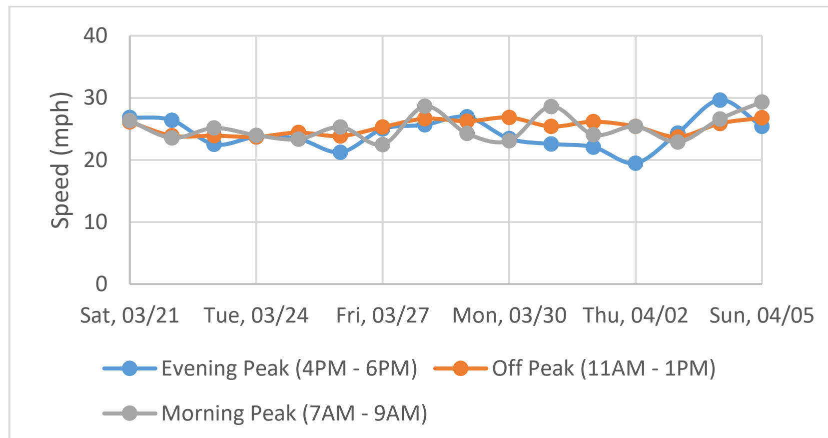


(b) Mar 21- Apr 05, 2020 (Period B)

Figure 9 Speed along West University Avenue (WB)

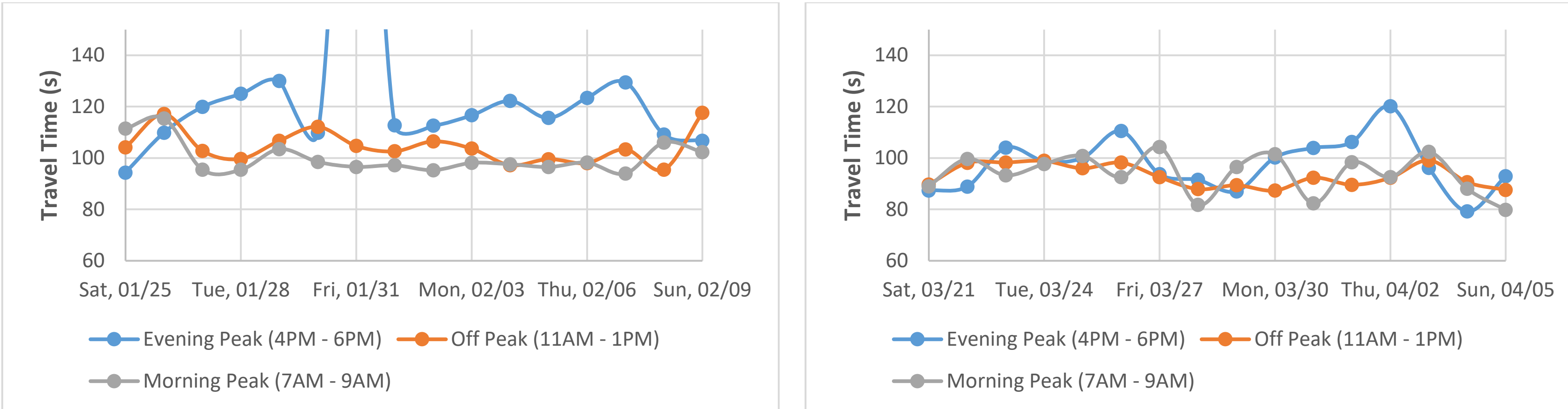


(a) Jan 25- Feb 09, 2020 (Period A)



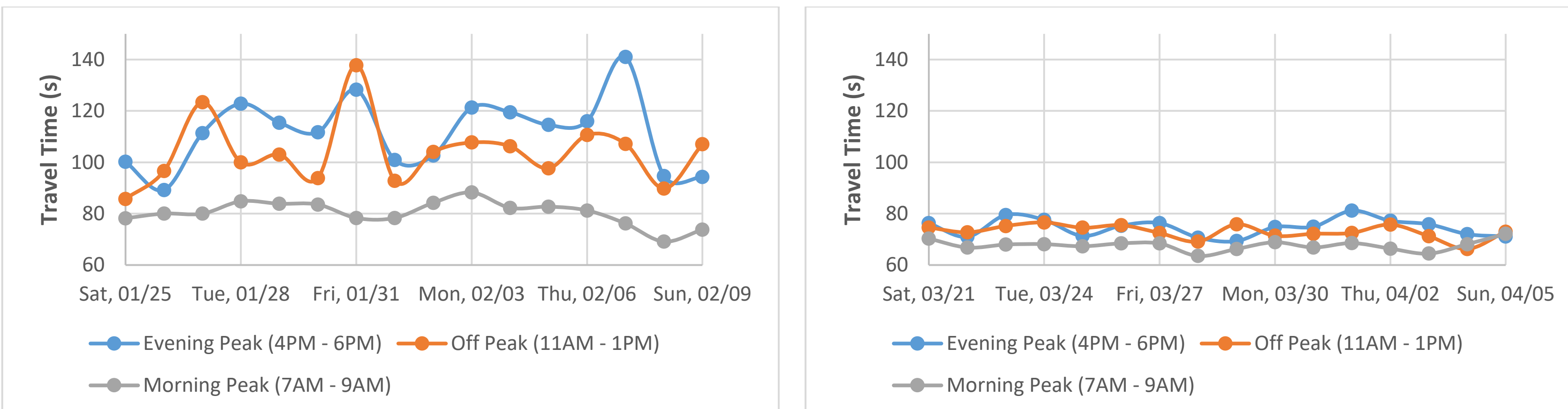
(b) Mar 21- Apr 05, 2020 (Period B)

Figure 10 Speed along West University Avenue (EB)



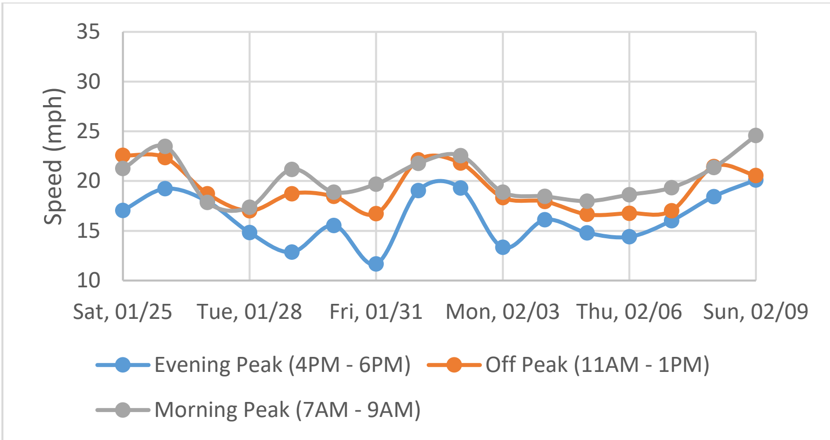
(a) Jan 25- Feb 09, 2020 (Period A) (b) Mar 21- Apr 05, 2020 (Period B)

Figure 11 Travel time along West University Avenue (EB)

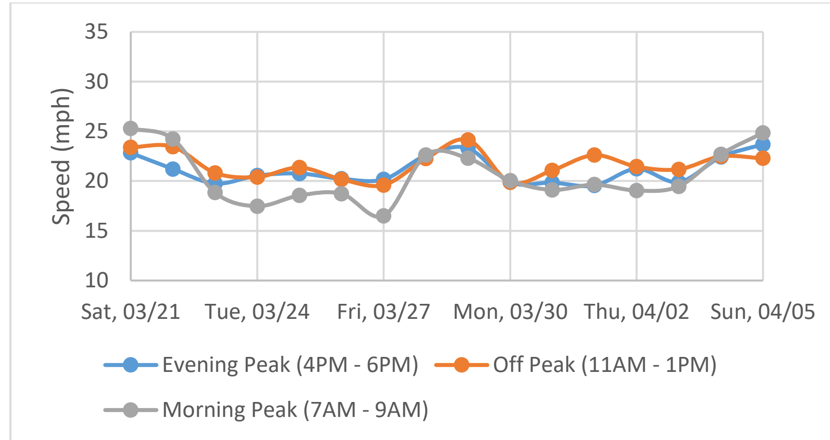


(a) Jan 25- Feb 09, 2020 (Period A) (b) Mar 21- Apr 05, 2020 (Period B)

Figure 12 Travel time along West University Avenue (WB)

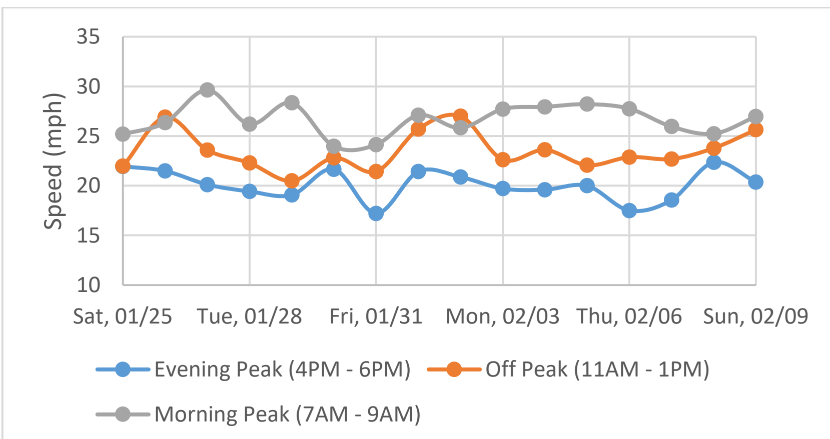


(a) Jan 25- Feb 09, 2020 (Period A)

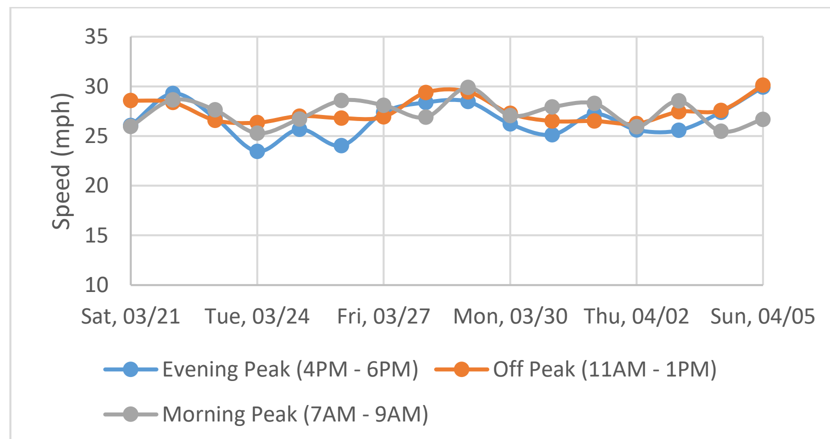


(b) Mar 21- Apr 05, 2020 (Period B)

Figure 13 Speed along 13th Street (NB)

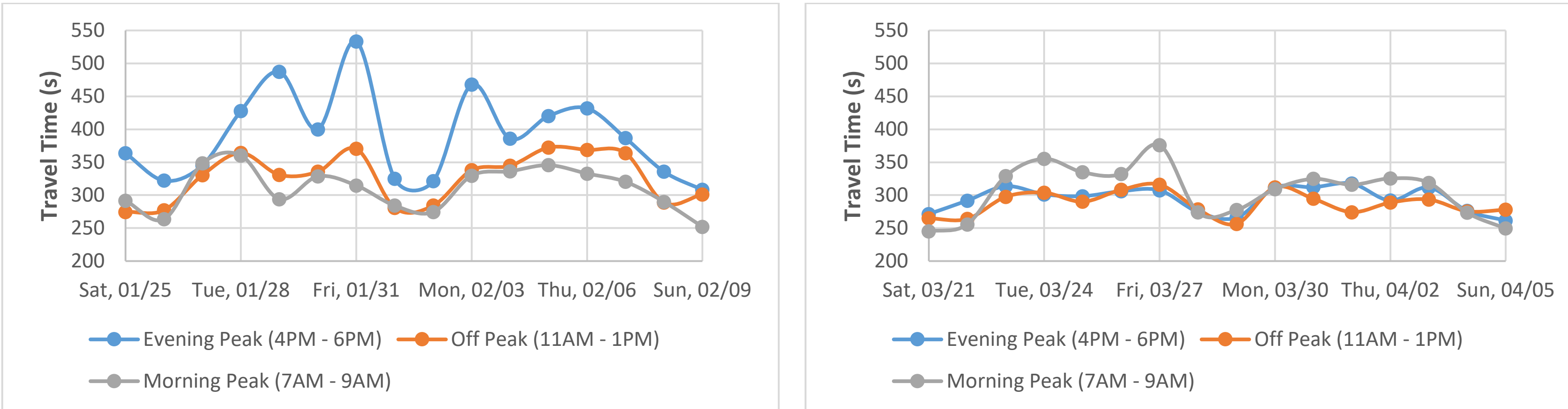


(a) Jan 25- Feb 09, 2020 (Period A)



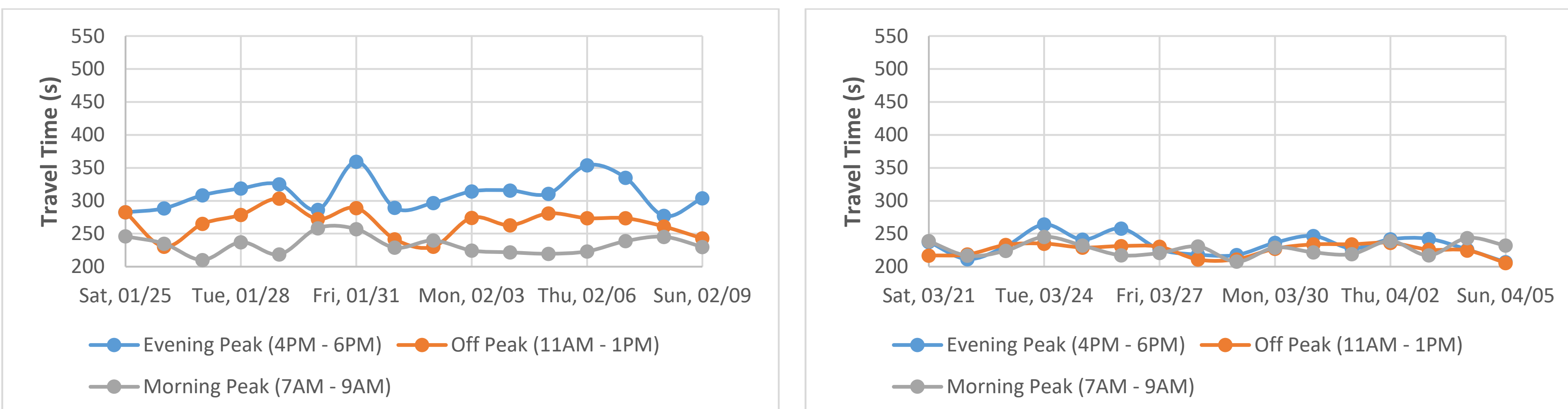
(b) Mar 21- Apr 05, 2020 (Period B)

Figure 14 Speed along 13th Street (SB)



(a) Jan 25- Feb 09, 2020 (Period A)   (b) Mar 21- Apr 05, 2020 (Period B)

Figure 15 Travel time along 13th Street (NB)



(a) Jan 25- Feb 09, 2020 (Period A)   (b) Mar 21- Apr 05, 2020 (Period B)

Figure 16 Travel time along 13th Street (SB)

3.5 Conclusions

The qualitative observations provided important insights regarding pedestrian experience, safety, and overall accessibility around the study network:

- Pedestrians were noncompliant with the rules of the road at many locations across the study network. The research team observed frequent jaywalking at mid-block segments, as well as walking across intersections when the pedestrian signal was red. Generally there seems to be a "climate of noncompliance", with pedestrians often crossing illegally.
- At some intersections, the pedestrians could not see the vehicles and vice versa, due to 2 mile obstructions such as trees, curvature of the road, etc. There are several warning signs for pedestrian crossings: however, there are no mirrors or warning signs to specifically address visibility.
- There are currently two mid-block crossings with flashing beacons.
- Some warning signs are placed close to (less than 10 ft) from the mid-block crossings. At locations where the bus stops are near or next to the mid-block crossing, the drivers behind the buses cannot see the warning signs.

The safety analysis concluded the following:

- A total of 1110 vehicle crashes, 49 pedestrian crashes and 48 bicycle crashes, were recorded within the study area between May 2014 and May 2019. The vast majority of these crashes were at or influenced by one of the several intersections along this corridor (there were very few crashes at midblock locations).
- Bicycle and pedestrian crashes at intersections are most likely to occur within crosswalks. In the majority of the bicycle and pedestrian crashes, the striking vehicle was traveling straight through the intersection, while crashes due to left-turning vehicles are also present.
- In pedestrian crashes, the driver of the vehicle and the pedestrian are about equally likely to be the "at fault" party in the crash. In the case of bicycle crashes, the driver of the vehicle is more likely to the "at fault" party in the crash compared to the cyclist.
- Over the months of the year, the crash trends mirror the university schedule with fall and spring semesters having more crashes than the summer. October is one of the top 2 months in terms of crashes for all pedestrians, bicyclists, and all vehicles.
- Among the days of the week, Fridays have more vehicle crashes and more pedestrian crashes, while midweek have more bicycle crashes. Pedestrian crashes are more frequent during the late-night periods while vehicle crashes in general occur between noon and 6 pm. Bicycle crashes are also more frequent during the early afternoon period.

The HCM analysis of three signalized intersections and one unsignalized intersection yielded the following conclusions:

- The most critical intersection along the West University Avenue corridor has a vehicular LOS of D though the traffic flow was much lower than normal (pre-COVID) condition. The pedestrian LOS of the signal is C.
- The other two signalized intersections have both vehicular and pedestrian LOS of B, but the traffic and pedestrian volumes were lower than normal when the field data were collected.
- The unsignalized intersection provided good quality of service (pedestrian LOS C). However, it has a high crash rate compared to other mid-block crossings.

The travel time and speeds were extracted from the BlueArgus database and the following are concluded:

- Two weeks of “pre” and two weeks of “post” COVID lockdown data were collected.
- With slower speeds and longer travel times, evening peaks are critical during weekdays.
- Post COVID data showed significant reduction in travel times when compared to pre-COVID conditions.
- Travel times were found to be almost constant across the time of the day for the “post COVID” analysis period.
- The high frequency of pedestrian crashes correlates with high travel speeds on W Univ. Ave.
- There is a high number of bicyclist crashes on 13^{th} St. during morning and off peak periods. This also correlates with high speeds particularly in the SB direction.

4 Evaluation of Hardware and Software for Passive Pedestrian Detection

4.1 Introduction

This chapter aims to provide the state of the art of pedestrian detection devices and Vehicle-to-Pedestrian(V2P) technologies.

Pedestrian detection and tracking involves determining the location of pedestrians through various sensors (video, radar, lidar, etc.) and their associated pedestrian identification algorithms (*1*). Methods such as “feature” descriptors for pedestrians were the traditional approach used for detection and they include Geometric hashing, Speeded Up Robust Features (SURF), Hough transforms, Scale Invariant Feature Transform (SIFT), and Features from Accelerated Segment Test (FAST). Machine learning models are recent pedestrian detection methods which are developed and then trained, tested, and evaluated on datasets obtained from sensors *(1)*. Deep Learning, a subset of Machine Learning, introduced the concept of end-to-end learning where the machine is just given a dataset of images which have been annotated with what classes of object are present in each image *(2)*. The following subsections review sensors, datasets used for their evaluation, and algorithms that are involved in pedestrian detection.

4.2 Sensors

According to the literature, pedestrians can be detected using ultrasonic sensors, radio detection and ranging (radar), video cameras (visible light and Infrared (IR), microwave radar sensor, and light detection and ranging (lidar). These sensors can be configured in different ways and embedded to vehicles or the infrastructure. There are advantages and challenges associated with each sensor technology. Table summarizes the pros and cons of various sensors used for pedestrian detection according to literature findings *(3, 4).*

Table 22 Pros and Cons of Detection Sensors (adapted from (*3*) *and ((4))*

Sensor	**Advantages**	**Disadvantages**	**Max. working distance**
Camera	Excellent discernibility Available for color distribution Can capture color, texture, and contrast. Processes information about lane marking, road signs, etc., to help safe navigation. Ability to detect vehicle types, pedestrians, and other road features through machine learning	Light interference Affected by extreme weather conditions such as rain and fog Data processing is relatively expensive	250 m (820 ft) (depending on the lens)

Table 22 Continued

Sensor	Advantages	Disadvantages	Max. working distance
RADAR	Applicable for all weather (less sensitive to extreme weather conditions such as rain and fog) Relatively cheap	Generating false alarm easily Cannot be used for static objects Signals can be blocked by an electric conductor. There is a possibility of communication interference due to crosstalk between sensors.	5 m-200 m (16 ft-657 ft)
Lidar	Wide field of view High range and angle resolution Provides a very precise distance Lane-keeping, parking assistance, blind-spot detection, adaptive cruise control, traffic-jam assistance, front–rear collision avoidance	Cannot be used in bad weather situations such as heavy rain High price Difficulty to use when dark	200 m (657 ft)
Millimeter wave-Radar (MMW)	Applicable for all weather conditions Available for radar velocity	Cannot be used for static objects Generating false alarm easily	5 m-200 m (16 ft-657 ft)

Since individual sensors have disadvantages, sensor fusion may be able to overcome their shortcomings. The use of multiple sensors such as, visible light and IR; cameras, laser scanners and RADARs; RADAR and monocular vision; camera-lidar(CL); RADAR-camera (RC); RADAR-camera-lidar (RCL) among others, either sequentially or in parallel can result in a stronger detection *(4)*, (*5*). Sensor fusion combats the weaknesses of individual sensors by merging their strengths (*6*), for instance improving precision and perception in CAVs (*3*). In the literature, there have been several experiments of sensor fusion. These experiments mainly display increase in accuracy of detection, as well as faster data collection and processing that lead to more effective operations. Table 23 shows the various pros and cons of fusion used for detection.

Table 23 Comparison of selected sensor fusion technologies used in pedestrian detection

Sensors	Advantages	Disadvantages	Evaluation	Authors
CL	Increased accuracy Ability to classify objects by shape, size and color Reduces false alarms	Dense depth map only depends on the lidar distance information	Fusion increases the accuracy of pedestrian detection to 82.9%	Premebida C., Asvadi A. et al, 2016 (7)
CL	Improves accuracy of the data produced Easy to implement Has an auxiliary effect on subsequent sensing steps Improves object detection at night.	Weak anti-interference performance	The processing time of each frame of data is reduced to 0.057 s; shorter than the response time of 0.2 s of human drivers	Guan, L et al., 2020 (8)
RC	Increase accuracy Inexpensive when compared to lidar Employs the exact distance to every estimation.	Mismatch error between radar detections and ground truth measurements	Outperforms Radar Region Proposal Network and Camera Radar Fusion-Net for the detection task with an Average Precision (AP) score of 0.15 and 0.54 points respectively	Nabati R., Qi H., 2021 (9)
RCL	Combats the adverse weather limitation Increased precision High data quality	It is complex	An improved Average Precision score by 5.1% when compared to single sensor such as lidar	Nobis, F., et al., 2021 (10)

Table 23 Continued

Sensors	Advantages	Disadvantages	Evaluation	Authors
MMW-RC	Increases accuracy System able to maintain accuracy in smoky, foggy and low-illumination conditions	Method cannot face regular and long-term occlusion of targets	Fusion reaches up to 46% Optimal subpattern assignment (OSPA) reduction	Wang T., et al, 2022 (11)

In addition to the vehicle- and infrastructure-based sensors, smartphone sensors (VRU-based sensors) have been used to obtain the pedestrian's position and heading to the surrounding vehicles. Data from a smartphone's accelerometer, magnetometer and gyroscope have been used in pedestrian detection and trajectory prediction (*12*). For instance, the magnetometer detects the direction of the magnetic north, and in combination with the GPS it can determine the user's location. The accelerometer can determine movement and orientation due to its ability to detect acceleration, vibration, and tilt. The gyroscope provides complex orientation details by identifying the rotation around the three axes (*12*). Results from experiments *(13)* show us that data obtained from smartphones regarding pedestrian position can aid GPS systems and increase accuracy, though testing in multiple environments is needed to corroborate this assertion. These methods can prove to be effective because magnetometer and accelerometer update information faster than GPS. Even though GPS can provide accurate information about pedestrians' location it is not energy efficient and reduces battery life rapidly *(13).* Therefore, it cannot always be turned-on by smartphone users. Recently, a method has been suggested that uses LTE network to locate pedestrians from their smartphone devices. Precision reached the levels of GPS while saving 20.8% of energy *(13)*. Research has been carried out to evaluate the performance of Wi-Fi Direct in V2P communications. A range of 525 ft was obtained and simulation experiments showed that collision can be avoided when vehicle travels at speeds up to 37 mi/h *(14)*.

4.3 Algorithms and Datasets for Evaluation of Pedestrian Detection methods

To evaluate and compare different sensing algorithms, researchers have developed and are using specific datasets. Most sensor data in the form of images, point clouds or the combination of the two must be processed and interpreted in order to make them useful in pedestrian detection (*2*).

The accuracy of the algorithm is dependent on the nature of the dataset used. If field data does not have the same quality as datasets that produce good accuracy, detection will be of lower accuracy. Constant efforts are being made to improve datasets to closely replicate the real world and to ensure the methods developed are robust. Table 3 depicts the most commonly referenced datasets in the literature.

Table 24 Most commonly referenced databases used to test pedestrian detection algorithms

Dataset name	Attributes
Karlsruhe Institute of Technology and Toyota Technological Institute (KITTI)	Collection of images from a combination of an in-vehicle dashboard camera and a lidar
Caltech Pedestrian Dataset	Collection of approximately 10 hours of 30 Hz video (~106 frames) taken from a vehicle driving through regular traffic.
CityPersons and EuroCity Persons (ECP)	Collected 2975 images for training, 500 and 1575 images for validation and testing. The average of the number of pedestrians in an image is 7.
Common Object in Context (COCO)	Downloaded images from the internet; the dataset has 2,500,000 labeled instances in 328,000 images.
PASCAL Visual Object Classes (VOC)	Provides standardized image datasets for over 20 different classes that are commonly used for object detection. Consists of 20 classes for annotation along with 11,530 images containing 27,450 ROI annotated objects.
Scene UNderstanding (SUN)	The database contains 397 categories. The number of images varies across categories, but there are at least 100 images per category, and 108,754 images in total.
ImageNet Large Scale Visual Recognition Challenge (ILSVRC)	Large visual database with approximately 14 million images contained in 20,000 categories downloaded from the internet
Korea Advanced Institute of Science and Technology (KAIST) Urban	Consists of 95,000 color-thermal pairs taken from a vehicle. All the pairs are manually annotated (person, people, cyclist) for the total of 103,128 dense annotations and 1,182 unique pedestrians.
nuScenes	Contains 1.4 million images, 1,000 scenes of 20s each and 390,000 lidar sweeps, all taken from vehicle-mounted sensors and cameras.
Oxford Robotcar	4.7 TB Dataset consisting of over 240,000 scans from 2 Velodyne HDL-32E 3D lidars, along with six cameras two 2D lidars and a GPS/INS receiver.
PandaSet	Data contained at PandaSet are captured by a gigabit camera. PANDA has 600 well

Table 24 Continued

Dataset name	Attributes
	annotated images captured from 21 diverse scenes for the multi-object detection task.

Deep Learning (DL) techniques which are a part of machine learning (ML) models are currently the basis of the most successful detection algorithms (*6*). DL methods have been shown to have greater detection accuracies, better training times and smaller range of calculations (*2*). (*15*) claimed that DL detection algorithms have limitations like having slower detection speeds, false detection could result due to overlaps and occlusions in the image, interference, and difficulty in detection due to appearance of objects in complex backgrounds. Even though the DL models are state-of-the art in pedestrian detection, selecting the right hardware for the detection using the DL techniques is greatly debated.

Detection algorithms in literature are divided usually into two categories. One-stage and two-stages detection algorithms. In two-stage object detectors, the approximate object regions are proposed using deep features before these features are used for the classification as well as bounding box regression for the object candidate. The two-stage architecture involves object region proposal with conventional Computer Vision methods or deep networks, followed by object classification based on features extracted from the proposed region with bounding-box regression. They tend to achieve higher accuracy predictions but are typically slower due to many inference steps per image. One-stage detectors predict bounding boxes over the images without the region proposal step. This process consumes less time and can therefore be used in real-time applications. One-stage object detectors prioritize inference speed and are relatively fast but not as good at recognizing irregularly shaped objects or a group of small objects.

Popular algorithms used to perform object detection include convolutional neural networks, Region-Based Convolutional Neural Networks (R-CNN), Fast R-CNN, and YOLO (You Only Look Once) *(16)*. The R-CNN's are in the R-CNN family, while YOLO is part of the single-shot detector family. In the following, we will provide an overview and differences between the popular object detection algorithms. Region-based convolutional neural networks or regions with CNN features (R-CNNs) are pioneering approaches that apply deep models to object detection. R-CNN models first select several proposed regions from an image (for example, anchor boxes are one type of selection method) and then label their categories and bounding boxes (e.g., offsets). These labels are created based on predefined classes given to the program. They then use a convolutional neural network to perform forward computation to extract features from each proposed area. In R-CNN, the input image is first divided into nearly two thousand region sections, and then a convolutional neural network is applied for each region, respectively. The size of the regions is calculated, and the correct region is inserted into the neural network. It can be inferred that a detailed method like that can produce time constraints. Training time is significantly greater compared to YOLO because it classifies and creates bounding boxes individually, and a neural network is applied to one region at a time. YOLO is a popular type of real-time object detection algorithm used in many commercial products by the largest tech companies that use computer vision *(16)*. The original YOLO object detector was first released in 2016 and the new architecture was significantly faster than any other object detector. Since then, multiple versions and variants of YOLO have been released, each providing a significant increase in performance and efficiency.

The most common choices for image processing in the applications of machine vision include Graphic Processing Units (GPUs), Central Processing Units (CPUs) and Field Programmable gate array [2] . GPUs are the most prevalent hardware choice for most DL models because of their significant speed compared to CPUs[3]. However, they are limited in the types of operations they can perform, they must be attached to Central Processing Units (CPUs), for handling everything else. GPUs work best where large computations are needed and have greater arithmetic capability and streaming memory bandwidth than CPU. However, many DL algorithms cannot run efficiently on CPU, which can be problematic since GPUs are not easy to deploy at the roadside due to their significant power requirements *(2).* Table 4 shows the processing units used by some of the state-of-the-art detection algorithms.

Table 25 Processing Units Used by Some of the Discussed Detection Algorithms

Algorithm	**Processing unit**
SSD	GPU
YOLO	Titan X GPU
SSOD	Dual CPU, NVIDIA 1080Ti GPU
R-CNN, SPPnet & Fast RCNN	GPU

The use of DL techniques are the recent methods in pedestrian detection. GPUs are the most common hardware preference for most deep learning, but the choice of hardware depends on the available task and the expected throughput and the cost. Also, some of the aspects to consider in choosing the suitable detection method include accuracy, localization, detection speed and independent use from CPU.

4.4 Evaluation of Pedestrian Detection Algorithms

Research has been conducted in order to test several algorithms for pedestrian detection. As mentioned before, different datasets have been used to test the effectiveness of the pedestrian detection methods. Initially, several performance measures were used. Nowadays, for detection accuracy, mean Average Precision (mAP) is used as evaluation metric for all these challenges. The mAP is the mean value of AP, which is calculated separately for each class based on recall and precision. The detector efficiency is also evaluated on Frame per second (FPS), i.e., how many images it can process per second. Commonly a detector that can achieve an inference speed of 20 FPS, is considered to be a real-time detector *(17).* Additionally, the average processing time in milliseconds per frame can be used, where the lower value, the faster the analysis procedure. Over the last few years, one-stage and two-stage detection methods have progressed to a significant extent. Nowadays, the most representative two-stage pedestrian detection algorithm is R-CNN series, including Fast R-CNN, Faster R-CNN, Cascade R-CNN , etc., with high scalability but complex structure and low speeds *(18).* These RCNNs are characterized by the concept of 'region proposal' based on pooling feature information in an image frame. Their performances depend on the accuracy in extracting the region's proposals *(19).* The most representative single-stage pedestrian detection algorithm includes YOLO series and SSD. However, with technical progress

[2] https://www.vision-systems.com/factory/article/14169567/cpu-or-fpga-or-gpu-for-image-processing-which-is-best
[3] https://azure.microsoft.com/en-us/blog/gpus-vs-cpus-for-deployment-of-deep-learning-models/

in YOLO series, single-stage detection algorithms are claimed to have outperformed two-stage detection algorithms not only in detection speed but also in detection accuracy *(18).*

4.5 Commercially available pedestrian detection systems

In terms of commercial deployments in this field, there are several companies that are competing in the space of video analytics and pedestrian detection.

Miovision Company promises to optimize a traffic network for efficiency as well as safety via the Miovision Detection solution. To be more specific, the solution offered by this company improves signal performance by responding to real-world road user demand, including bicycle and pedestrian demand. Additionally, it offers multimodal detection at the intersection and advance detection for approaching vehicles, and it is designed for all environments. It claims to have twice the computing power of its competitors and also states that the detection accuracy reaches 98%, exceeding Traffic Engineering Research Laboratory (TERL) standards *(20)*.

Currux Vision’s SmartCity & Intelligent Transportation Solution is a fully integrated artificial intelligence (AI) hardware/software solution for detection, video analytics, and incident detection. The system used AI servers deployed at traffic cabinets or local server rooms and transmit metadata to a central server. Powered by machine learning, video streams are processed on Currux Vision and made available to the customer. Currux Vision also is able to predict trajectories speed, and distance of cars as well as pedestrians to inform customers about potential accidents and danger zones. Traffic safety data are presented in reports, and real-time near-miss notifications are issued. As far as accuracy is concerned, the company claims that accuracy reaches 95% and speed is measured within 2 mph deviation *(21).*

Yunex-Bosch company has developed the Yunex Traffic “awareAI” System; a smart camera system with artificial intelligence focusing on detection, classification, and tracking of road users, including pedestrians, bikes, cars, trucks, and busses. All detection tasks are performed within the local processing unit, guaranteeing the high level of data protection because only fully anonymized information is processed by external systems. Typical application examples include crosswalk supervision in order to actively initiate green phases for waiting pedestrians and cyclists, without needing to use manual push buttons at intersections, and traffic counting where specified objects (pedestrians, cars, etc.) can be monitored, and their positions can also be processed and visualized as cumulative trajectories *(22).*

Derq company has come up with Derq Sense, a solution that provides customers with real-time infrastructure-based analytics. Detection enables connected autonomous vehicles (CAVs) to predict dangerous conflicts with pedestrians and other vulnerable road users (VRUs). It also provides adaptive traffic management as well as smart pedestrian crosswalks. While detecting them, there is no need to manually press the button to actuate flashing beacons. Derq claims that the accuracy of the system is high and complies with automotive standards *(23).*

Cubic Transportation Systems has presented GRIDSMART Protect System, a system able to detect pedestrians and bicyclists. Detection is utilized to modify signal timings and ensure safe passage of VRUs through intersections. This is ensured by retiming traffic signals to extend clearance intervals. Ultra-wide-angle-lens cameras coupled with a ruggedized cabinet mounted processor provide not only detection but also data collection and processing. Software resides in the processor and accounts for algorithms that make all the state-of-the-art features work and provide analytical details of what is taking place *(24).*

As discussed above, most of the companies reviewed, claim various detection rates and successful deployments. There is a need to evaluate these technologies independently. For example, if deployed on the same intersection/corridor how would their performance compare to each other as well as open-source tools such as YOLO and CNNs. This is a research questions that has the potential to inform widescale deployment of such sensors.

4.6 Conclusions

Various sensors have been used for pedestrian detection and there is no single perfect sensor since each of them have their own advantages and disadvantages. Sensor fusion helps to combat the weaknesses of individual sensors by merging their strengths.

There are several datasets that have been used to evaluate pedestrian detection algorithms. The databases consist of sets of pedestrian images with different sizes (in number of pixels) of labels (the pedestrian) relative to the whole image. The developed detection methods are trained and evaluated using these images. The PASCAL VOC dataset that is widely used in literature, and the ImageNet so far yields the highest accuracy in pedestrian detection due to the large sizes of their labels which are easy to detect. There does not seem to be a best dataset for pedestrian detection algorithms evaluation but the INRIA dataset is still considered the most popular for pedestrian detection *(25), (26)*. However, if field data do not have the same quality datasets that produce good accuracy values, detection will be of lower quality. Thus, it is necessary to establish a dataset that replicates the real-world field scenario to ensure that as the algorithms are improved, they become robust to real life implementation to improve safety.

Further, some of the evaluations of algorithms and the values of accuracies (e.g., 79.4% for SSOD) are based on databases, such as PASCAL VOC, with easier identifiable labels. A thorough reference point can be developed to compare and rank the current and future detection algorithms. Since most of the available state-of-the-art pedestrian detection algorithms have been evaluated on different datasets, it is difficult to choose the best detection algorithm as the best dataset has not been established yet.

In terms of commercial deployment, the companies claim various detection rates and successful deployments. These rates have not been confirmed by independent studies. It would be of value to evaluate them and compare with pedestrian detection algorithms such as YOLO and CNNs.

.

5 Evaluation of Hardware and Software for the Smartphone Application

5.1 Introduction

This chapter aims to provide information regarding the state of the art in smartphone applications for pedestrian safety. To be more specific, it aims to inform the readers about the utilization of smartphones as sensors, as well as message delivery devices. Delivery of warnings that result in a necessary action by either the driver or pedestrian to avoid a potential crash is the last and crucial component in some Vehicle to Pedestrian(V2P) systems.

Upon the detection of a possible collision, the application's pedestrian collision avoidance system initiates a consequent action either by the vehicle or pedestrian to avoid the collision. The action could be automatic emergency braking, or provision of warning/alerts by either the vehicle, pedestrian or both based on the structure of the V2P system.

5.2 Pedestrian-based warnings

The following two sections review the warnings sent to pedestrians (pedestrian-based warnings) and to drivers (vehicle-based warnings). The review covers the technology involved, the type of warning conveyed, and existing challenges and recommendations for future improvements and effective implementation.

Handheld devices such as smartphones are the most obvious alert system for pedestrians *(27)*. The smartphone alert systems have been developed for different crash scenarios through different studies. The pedestrian may be alerted by a vibration or notification sound *(27)*. The warning messages could be conveyed to the pedestrian through auditory instructions, visual instructions or spatialized sounds *(27)*

A smartphone V2P system app, Walk N Text, that uses a camera for detection was developed and the app targets pedestrians who use their phones (texting, playing games, accessing social media) while walking (28). Pedestrians use the rear-facing camera to watch vehicles ahead, and they can activate their flashlights at night for night detection. The system addresses the forward crashing scenario when the pedestrian is in a straight line with an approaching vehicle both during the day and night. The pedestrian is expected to act once they spot an approaching car using the camera. However, while pedestrians use their phones, the camera generally faces down, and for collisions to be prevented using this app, the pedestrian needs to point the camera forward/backwards or sideways.

A V2P connectivity application that alerts pedestrians about the presence of vehicles near them was created *(29)*. The article centers the development of the V2P communication system on a typical scenario where a pedestrian crosses in front of an idling bus where he/she is obstructed from an incoming vehicle in the same direction. The study provides a Graphical User Interface (GUI) that enables the user to be aware of the service and personally manage the settings. The smartphone application provides notification if the distance between the user and the vehicle is below a particular value based on the real-time position of the vehicle as shown in Figure 17. The author tested the application following the agile principle. The agile principle involves creation of a mobile application in small iterations each of which consist of gathering requirements, designing the app, developing it, conducting exploratory testing, deploying, and reviewing the application. The exploratory testing facilitates debugging to achieve an effective application for the desired scenarios [4]. Based on the test results, the application worked correctly. Although there was a loss of messages that was not captured by the V2P algorithm, the system sent messages every 90 milliseconds which was considered more than enough for a V2P application *(29)*. Although this seemed like a great start, the method was not implemented and tested in the field and thus it is difficult to tell the effectiveness of the application in the real world for preventing possible pedestrian crashes.

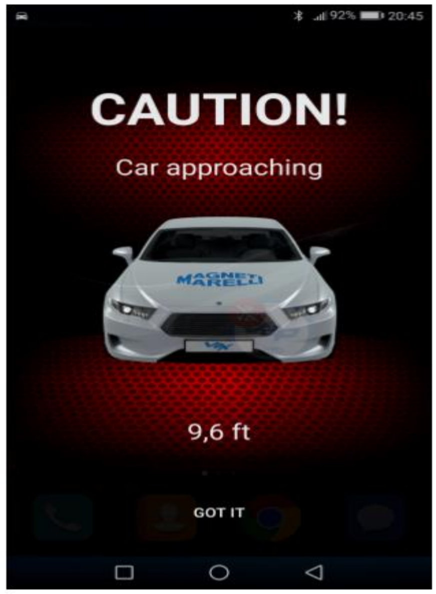


Figure 17 Notification screen (6).

Investigation was conducted on the response of texting-pedestrians to traffic warnings delivered in their smartphones that informed them when it was safe to cross the road *(30).* The results were later compared to a control group (non-texting pedestrians) and to texting pedestrians who did not receive any alerts. The texting-pedestrians received alerts that provided them with the information of a safer crossing gap of 4–4.5 s as shown in Figure 18 where panel A shows a countdown clock in red and panel B shows a safe crossing gap with a green box. The results showed that texting-pedestrians receiving warnings did not pay much attention to the traffic like the other two groups of pedestrians who spent most of the time checking the traffic before crossing. The technology might reduce situation awareness for texting-pedestrians which could be dangerous when unforeseen circumstances or failure of the warning system happen *(30)*. Although these results offer promise for the use of mobile communications technology in promoting safe road crossing, the degree to which participants in the warning group focused on the cell phone raises concerns about overreliance on technology for guiding road crossing.

Later, instead of permissive warnings, a study created a cellular V2P background warning system that cautions pedestrians through prohibitive beeping alerts when they begin to make unsafe crossings and tested it in a pedestrian simulator *(31)*. The objective was to observe the effect that texting has on the behavior of the pedestrians while crossing the road, and the efficacy of warnings in decreasing unsafe road crossings in texting-pedestrians. However, the results show

[4] https://www.knowledgehut.com/blog/agile/exploratory-testing-agile-software-development

that only 41% of the time the participants heeded the alert of the unsafe crossing, and most pedestrians did not heed the prohibitive warning once a crossing was initiated. The authors found that texting influences how pedestrians select road crossing gaps, their gazing behavior and timing of movements, and the warnings help enhance decision making and safety *(31)*. However, there is a limit to warning texting-pedestrians when they have already started to cross the road. Further improvement is required in the timely delivery of prohibitive warnings and the design of interfaces to convey required information to pedestrians effectively.

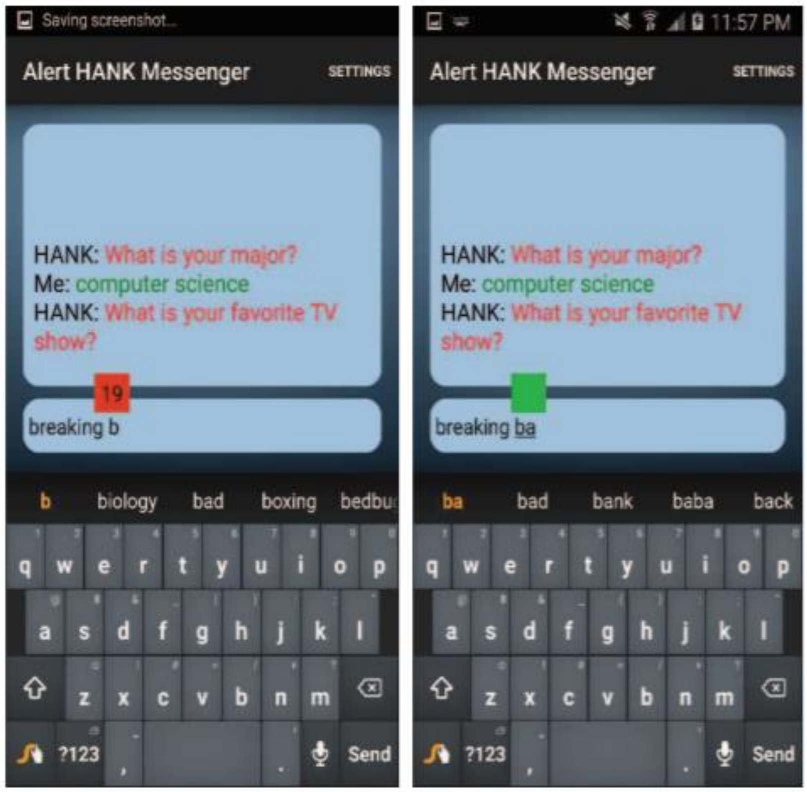


Figure 18 panel A showing a countdown in red and panel B showing a safer crossing gap (adapted from Rahimian et al., 2016)

Previous studies have also examined effective visual presentations for warnings ideal for human response. Prior research showed that background color affected the perception of hazard, and the possibility of obeying warnings *(32)*. The highest level of perceived danger, behavioral compliance, severity, and immediacy of consequences was seen from a red background. For prohibitive symbols that are always red, a black background was found to be more effective. However, colors can be challenging for people with color blindness and other color-related health problems, thus auditory accompaniments could be necessary (*(33)*. The auditory and visual methods of conveying warnings to pedestrians bear some limitations for example visual instruction might be a source of distraction to a pedestrian hence undermining the pedestrian's safety *(32)*. Visual instructions may be difficult to interpret and require effort to match the given information to the environment. Auditory instruction on the other hand is more convenient but may be difficult to perceive when the pedestrian is in a loud outdoor environment. Auditory instruction may also reduce the level of concentration of the pedestrian to conversations with other pedestrians *(32)*. In cases where swift responses are required, visual and auditory alerts can be conveyed concurrently *(34)*. Therefore, it is considered important to incorporate simultaneous delivery of both audio and visual alerts in the design of the person-machine system interface to enhance safety, accuracy, and efficiency of the system *(34)*,*(35)*.

Visual and audio alerts have been implemented to warn pedestrians about crossing an intersection with the use of Bluetooth beacons *(36)*. *(36)*, installed beacons around intersections and utilized StreetBit smartphone application to avoid collisions. Pedestrians paying attention to their phones, either texting or watching something on their screen received alerts. The study received positive feedback from the participants and also presented high level of accuracy. From the post-survey questionnaire, about 70% of people thought that using the StreetBit app was worthwhile for their health and safety. More than 80% of users did not find StreetBit annoying and more than 69% of users would recommend StreetBit to others. Table 1 provides an overview of the reviewed pedestrian-based warnings. It was noticed that all warning systems that aim to alert pedestrians utilize smartphones as the mean for delivering them. So, it is necessary that pedestrians own a cell phone equipped with technology such as GPS and it is needed that the cell phone is not turned off. Some of them require that pedestrians actually use their smartphones while trying to cross a road. The problem with these applications is that they have other prerequisites in order to be effective such as holding the smartphone at a certain position or i.e. do not cover the smartphone's camera.

Table 26 An overview of the pedestrian-based warnings

Method	**Technology**	**Alert Scenario**	**Alert style**	**Pros**	**Cons**
A smartphone V2P system app: Walk N Text	Uses rear-facing camera for detection	Pedestrians using phones while walking to address forward crashing scenario	Pedestrians watching for oncoming vehicles through the camera	Considers pedestrians using their phones while walking	Cameras generally faces down when pedestrians use phones
A smartphone application	A V2P algorithm	Pedestrian crossing in front of an idling bus and is obstructed from an incoming vehicle in the same direction	Visual notification when the distance between pedestrian and vehicle is below a certain value	Successful method based of agile principle	Not tested in the field

A cellular V2P background warning system	Cell phone and GPS	When pedestrians initiate unsafe road crossings	Prohibitive beeping alerts	Warnings enhance decision making and thus, safety	Once most pedestrians initiated an unsafe crossing, the warnings did not stop them
A Cellular-based V2P Collision Warning Service	A V2P server	When a dangerous event is reported from a vehicle	Sound or Vibration	Enables an energy-efficiency positioning method	Pedestrian's phone needs to have energy efficient outdoor positioning method
Bluetooth Low Energy (BLE)	Bluetooth Beacons and StreetBit application	Pedestrians engaged in an application/talking/listening to something and approaching an intersection	Sound or Vibration	Inexpensive installation Energy efficient for smartphones	Beacons installed vulnerable to rain, extreme heat/cold and potential theft/damage

5.3 Vehicle-Based Warnings

There are two types of vehicle-based warnings: advisory warnings and imminent crash warnings. The advisory warnings alert the driver of a possible collision and prepare him/her to respond while the imminent crash warnings focus on the immediate reaction to avoid collision by the driver. The means used to alert the driver include visual displays, acoustic signals, voice messages among others *(37)*. The following section reviews the vehicle-based warnings reported in the literature to avoid possible crashes with pedestrians.

There are some applications that are developed to alert the driver of an autonomous car on pedestrian's location to prevent collision with pedestrians. The Federal Transit Administration (FTA) developed a V2P technology to lessen pedestrian crashes involving transit vehicles. In 2017, the Enhanced Pedestrian Crossing Warning (E-PCW) application was developed in Cleveland, Ohio. The E-PCW alerts bus drivers when pedestrians are in a signalized intersection or crossway and are in the lane of the bus *(38)*. The results showed that the alerts improved the response rate of drivers by over 16% as braking was made within 2.5 seconds. Also, the reaction time for the transit drivers was reduced to 1.3 seconds from 1.6 seconds. Generally, the E-PCW operation was effective and viable for transit and pedestrian safety improvement *(38)*.

Wu et al. *(39)* designed a DSRC based system for V2P connectivity where both the pedestrians and drivers receive safety message information to prevent possible collision. The message contains information about the location of the driver and the pedestrian based on the in-vehicle device and the VRUs device (smartphones). Field tests were carried out at an intersection for various pedestrian safety scenarios; the non-line of sight where a building and a large vehicle blocks the direct line of sight between the driver and pedestrian, and the line-of-sight scenario. The results showed that for a 492 ft communication range where the vehicle is traveling at 32.8-65.8 ft/s, the vehicle had enough time (7.5 to 15 s) to be aware of a pedestrian's presence and avoid impeding collision (*39)*. However, DSRC experiences challenges of channel congestion when there are many transmissions. Nonetheless, *(39)* argued that, timely delivery of messages is not possible due to channel congestion but prioritizing the most crucial nodes is important for reliability of V2P systems. Also, there was the issue of mobile positioning accuracy where a smartphone has limited power capability for the geographical positioning system (GPS) under comparable conditions (39).

A case study by *(40)* explored a cycle eye technology that was developed to tackle the blind spot issue (restricted field of view of the mirrors) of transit buses. Drivers get warning alerts when pedestrians approach the bus. The system combines camera and radar technology to distinguish cyclists from other objects such as other vehicles, and lampposts, and provides an audio warning to the driver. The cycle eye technology was tested in Bristol, London covering all weather scenarios, day, and night. Based on the test, the technology poses some benefits, for instance, the audio alert helps drivers by reducing their thinking burden which enables them to respond swiftly in dangerous scenarios. However, it is not clarified how the units can sustain extreme weather conditions.

A study on the prototype of pedestrian-to-vehicle communication system was developed. The system uses a cellular phone and a car navigation system equipped with GPS and wireless communication function. The interoperation of wireless LAN and 3G wireless network allowed communication in a vast area with little delay time. This system allowed pedestrians and vehicles to exchange relevant information. The system provides information of the location of those that have a possibility of collision and gives a warning by using the developed algorithm to estimate the collision risk between each pedestrian and vehicle. The system was tested for effectiveness through traffic situations simulation. However, the algorithm is to be improved to determine the appropriate time for warning depending on the traffic situation to ensure effectiveness[5].

The American Automobile Association (AAA) evaluated the technology of the Automatic Emergency Braking System (AEBS) with pedestrian detection functionality. The research assessed the system for different scenarios. First, it examined its performance at night and found that it was ineffective since the vehicle hits the pedestrian. Second, the performance of the system was tested when unexpectedly meeting an adult pedestrian crossing perpendicularly, when a child pedestrian dashes from parked vehicles to the roadway, and when a vehicle approaches two adult pedestrians along the road. The research found that the system provided a visual alert of an impending collision when a pedestrian crosses perpendicularly while the vehicle was traveling at 20 mph and crashes were avoided 40% of the time. The collision was avoided 20% of the time

[5] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4556313&casa_token=XSx31-1V7g0AAAAA:U5cyoY13LAp4t3hUVbjFH4inLruCS0R-5hJZyZKAyxlwBkZTLtEs1W4sTfNSjCIf3HWJsIlAKQ&tag=1

mile when the vehicle was moving at 20 mi/h alongside two adult pedestrians, and 11% of the time when a child dashes from parked vehicles. Finally, the study assessed a scenario when a right-turning vehicle encounters a crossing pedestrian. However, collision with a pedestrian was not avoided in the right-turning scenario. Even with pedestrian detection systems, the collision was not fully mitigated in most scenarios that were evaluated which implies that drivers should not completely rely on the emergency brake system, rather it should be a backup. Thus, further research should be conducted to improve the effectiveness of this AEBS pedestrian detection system especially at night *(41)*. Table 2 shows an overview of the reviewed vehicle-based warnings to prevent collision with pedestrians. It can be noticed that most Vehicle-Based Warnings need the same element as Pedestrian Based warnings in order to be effective; the possession of a smartphone, turned on with an active localization system. This fact raises similar concerns to warnings for pedestrians. In addition, the driver's reaction time is a significant factor that determines the effectiveness of these kinds of applications. As a result, warnings should be initiated at a certain time that considers this short time span.

Table 27 An Overview of Vehicle-Based Warnings

Method	Technology	Alert Scenario	Alert style	Pros	Cons
E-PCW application	DSRC	Alerts bus drivers when pedestrians are in a signalized intersection or crossway and are in the lane of the bus	Visual and/or sound alert	Transit driver's reaction time reduced from 1.6 to 1.3 seconds	Alert accuracy needs improvement
Intelligent night vision	Infrared Camera	Presents road condition ahead when vision is limited	-	Able to reduce possible occurrences of accidents	Higher recognition rate needs to be achieved
DSRC-based V2P system	DSRC	LoS and NLoS	Visual and/or sound alert	Both Drivers and pedestrians receive warnings	DSRC channel congestion Limited smartphone power capability or GPS
Cycle eye technology	Camera and RADAR	Blind spot in transit busses	Audio warning	Audio alert helps drivers by reducing their thinking burden which enables them to respond swiftly in dangerous scenarios	The systems performance in extreme weather condition is unknown.

Pedestrian-to-vehicle communication system prototype	Cellular phone, car with GPS and wireless communication function	Provides information about location of pedestrians and drivers	Exchange of information between drivers and pedestrians	Reduces possibility of collision	Determining appropriate time for warning is a challenge
AEBS	Camera/Radar	Night condition, pedestrian crossing perpendicularly, child dashing from parked vehicles	Visual and auditory warnings	Satisfactory results during daytime/nightime	Insufficient operation during adverse conditions (rain, dirt on window etc)

Pedestrian safety partly relies on the driver's behaviors and the vehicle conditions. Most crashes result from the driver's inattention, lighting conditions, weather, and location. Vehicle-based V2P system warnings, whether they be visual, auditory, or a combination of both, were developed to alert drivers, or enable vehicles to act on any potential collision. Based on the above discussion, various vehicle-based warnings have been created for different scenarios, such as drowsiness, blind spot, driver inattention, driver's reaction time, and locations like signalized intersections with an ultimate goal of improving safety while avoiding collision with pedestrians. Some of these technologies have been successful: however, visual vehicle-based warnings may not be very effective due to distractions that result in increased response time.

5.4 Existing Commercial Deployments

The aim of this section is to provide information regarding V2P systems that can detect pedestrians and are available for sale.

Volvo Company has released new technology that detects pedestrians and applies the brakes of the car instantly. For this task, a camera and radar are fitted in front of the interior rear-view mirror along with a central control unit. The camera-radar combination has a wider field of vision, allowing the system to detect pedestrians about to cross a road. The central processing determines if objects detected are pedestrians. Warnings are generated if there is a potential collision *(42).*

Mobileye has developed a system that uses a camera mounted on the inside of the windshield behind the rear-view mirror (Mobileye8-Connect) to detect pedestrians. EyeWatch, mounted in the bottom corner of the windshield displays a visual alert and also generates audio alerts. The system calculates the estimated time to collision (TTC), and when it drops below 2 seconds, alerts are generated *(43).*

Traficon USA along with Kar-Gor Inc. have released Safewalk, an above-ground sensor for pedestrian detection *(44).* This sensor is designed to view a detection zone adjacent to the pole to which it is mounted. By detecting waiting pedestrians and, at the same time, by managing and controlling traffic lights more dynamically, this intelligent sensor reduces unnecessary delays to both pedestrians and motorists. The stereovision video image processing technology is used for the detection and monitoring of pedestrians who are waiting to cross the street within a user definable zone. In addition, SafeWalk can hold the red time for pedestrians for as long as there is no pedestrian presence, making traffic flow more fluent and efficient *(44).*

Toyota has equipped its new vehicles with Toyota Safety Sense, a system designed to avoid collision with pedestrians and bicyclists. To avoid collision, the system utilizes a fusion of a camera and a radar mounted in the front of the vehicle. This integration allows the system to detect pedestrians present in front of the vehicle. Under conditions where the system determines that possibility with a pedestrian detected is high, it prompts the driver to act and brake by using audio and visual alerts *(45).*

Ford Motor Company has developed a system that utilizes sensors that detect pedestrians to assist drivers avoid collisions. The system uses radar and camera integration that scan the road ahead and, in case a pedestrian is detected, a row of warning lights illuminates on the windshield. The warnings also include audio alerts *(46).*

Nissan also has released a similar system where a front-mounted camera installed in the upper-portion of the windshield detects the presence of vehicles and pedestrians. If any are detected, it measures how far away they are. The system then determines if there is a risk of collision from the speed of the vehicle and the distance and speed to the vehicle or pedestrian ahead *(47).*

AEye Inc., based in Dublin, Ca has created a platform able to detect pedestrians using lidar. AEye's 4Sight™ M is a software-defined lidar sensor specifically designed to complement the use of existing cameras, radars, and loops in Smart Intersection applications, improving data collection and overall safety for road users and pedestrians. It claims to have a detection range of over 984 ft and precise high speed pedestrian detection. After data has been collected, they are sent to traffic controllers for further actions. The operating system is sensor-based, and it enables transmitting and receiving signals separately allowing optimization for both. 4SightM, has already been deployed at intersections throughout the US such as Sarasota, FL *(48).*

Derq Company has developed Derq Sense, a platform that collects and analyzes data from traffic sensors to improve Traffic Safety. To be more specific, the platform analyzes behavioral patterns of vehicles, pedestrians, and traffic flows in real-time to identify and predict potential road incidents. It can then generate the appropriate Connected Vehicle message to alert distracted driver from colliding with a pedestrian about to cross the road. V2X messages are generated with ultra-low latency and high positional accuracy in compliance with automotive standards. Platform has been implemented at various locations worldwide; US locations include California, Florida, Ohio, Colorado, Michigan, Texas, Nevada *(49)*.

Furthermore, Cubic Transportation Systems has presented GRIDSMART Protect System, a system able to detect pedestrians and bicyclists. Detection is utilized to modify signal timings and ensure safe passage of VRUs through intersections. This is ensured by retiming traffic signals to extend clearance intervals. Ultra-wide-angle-lens cameras coupled with a ruggedized cabinet mounted processor provide not only detection but also data collection and processing. Software resides in the processor and accounts for algorithms that make all the state-of-the-art features work and provide analytical details of what is taking place. System has been implemented in Huntington, NY *(50).*

Yunex Traffic has invented a platform that aims to improve Traffic Safety through pedestrian tracking data collection. To be more specific awareAI is a smart camera system with Artificial Intelligence to detect and track pedestrians in flexible detection zones. Using infrared illumination built into IP cameras, both standing and moving road users can be detected and tracked by the awareAI System even during adverse lighting conditions. Using the integrated artificial intelligence engine, the standard awareAI System detects and classifies at least eight different object types. The local processing unit awareAI Core is responsible for the processing of imagery from IP cameras. Depending on individual application requirements, awareAI Core transmits the fully anonymized object data for further processing or data analysis, such as to a server unit or a traffic control center. Table 3 presents the most up-to-date platforms (to the knowledge of the authors) that can detect pedestrians and generate collision avoidance warnings *(51)*.

Applied Information Inc. has developed a smartphone application that uses cutting edge technology to connect smartphones to a network of traffic intersections, beacons, motorists, cyclists and pedestrians. The app uses audible warnings to alert road users for potentially dangerous road conditions. By utilizing spoken alerts, TravelSafely allows the user to focus on the road and its surroundings. As far as pedestrians are concerned, users equipped with the application, are alerted of speeding vehicles approaching and other dangerous conditions such as vehicles passing with a red light. In general, Personal Safety Messages (PSM) are generated for a wide range of scenarios with the aim of reducing road accidents and fatalities *(52)*. Travel Safely application is implemented as part of the Gainesville deployment. It will be evaluated by the research team in terms of both technical aspects of the application and its usability, perception and usage of the application via survey and a focus group experiment.

Since September 2015, the Tampa Hillsborough Expressway Authority (THEA) has been working with the United States Department of Transportation (USDOT) as a Connected Vehicle (CV) Pilot site. The THEA CV Pilot was the only program in the country implementing real-time, Vehicle-to-Infrastructure (V2I), and Vehicle-to-Vehicle (V2V) communications. The CV Pilot was considered as successful and the USDOT has asked THEA to continue on to the next phase in the Connected Vehicle Project space and begin working with the auto industry manufacturers. THEA is now collaborating with Honda R&D Americas, LLC, Hyundai America Technical Center, Inc. and Toyota Motor North America to deploy vehicles with connected vehicle technology already installed. The pilot has been tested at the East Twiggs Street, Tampa, Florida. When sensors detect a pedestrian in the crosswalk, roadside equipment broadcasts that information to nearby connected vehicles. If a vehicle's speed and direction indicate a potential collision course with the pedestrian, the driver receives an alert *(53)*.

New York City is one of three Connected Vehicle (CV) pilot deployment sites selected by US Department of Transportation (USDOT) to demonstrate the benefits of the Connected Vehicle technology. The New York City deployment focuses on the vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and infrastructure-to-pedestrian (IVP) communications. The NYC CVPD deployed two pedestrian oriented applications: 1) a generalized warning to vehicles of pedestrians in the roadway and 2) support for visually impaired (blind) pedestrians. The first application uses pedestrian detection information to indicate the presence of pedestrians in a crosswalk at a signalized intersection. As a vehicle passes by a signalized intersection, the pedestrians are detected by the traffic control system. At the same time, the pedestrian will carry a personal information device (PID) in the form of a smartphone which will communicate with the New York City Connected Vehicle infrastructure. The pedestrian detection information is sent to and processed by the radar scene emulator (RSE), which will then broadcast it to the onboard units (OBUs) in the vehicles *(54)*.

Table 28 Commercial Platforms for Pedestrian Detection

Company	Sensor Location	Type/s of Sensors	Pedestrian Detection	Alert Style/Communication Path
Volvo	Mounted in rear-view mirror	Camera/Radar	Radar detects objects, camera determines whether it is a pedestrian	Visual and audio alerts
Mobileye	Mounted on the windshield of vehicle	Camera	Leverages crowdsourcing to grow dataset	Audio Alerts when estimated Time To Collision is below 2 seconds
Traficon-Kar-Gor Inc	Mounted on existing infrastructure	Camera and Detector	Stereovision 3D technology	Modification of Traffic Signals to serve pedestrian flow
Toyota	Mounted in front of the vehicle	Camera/Radar Fusion	Able to detect pedestrians during low-light conditions	Visual and audio alerts
Ford Motor Company	Mounted in rear view mirror	Camera/Radar fusion	Technology that predicts pedestrian trajectory	Visual and audio alerts
Nissan	Mounted on the windshield of vehicle	Camera	Estimated how far pedestrians are located and determines the possibility of a potential collision	Automatically applies the brakes
AEye	Mounted on poles/gantries	Lidar	Detection under adverse weather conditions while retaining high resolution and accuracy	Data collection and dispatch to Traffic controllers to share with OBUs and VRUs
Derq Traffic	Mounted on existing infrastructure	Traffic Sensors	AI-powered processes after data collection to detect and report pedestrian activity	Generates messages to CAVs to avoid collisions with pedestrians
Cubic Transportation Systems	Mounted on existing infrastructure	Cameras	Ultra-wide-angle-lens cameras	Modification of Traffic Signals to serve pedestrian flow
Yunex Traffic	Mounted on poles/gantries/building façades	Camera	Smart Camera system with its own processing unit	Data distribution to optimize traffic controllers with respect to pedestrian safety

Travel Safely App	Smartphone	PID	Communication between a Connected Vehicle Network	Visual and audio alerts
NYC CV Pilot	Smartphone	PID	Communication between a Connected Vehicle Network	Visual and audio alerts

6 Behavioral Observation – Based Evaluations through Focus Groups, Participant Experiments, and Surveys

This chapter presents the research plans to evaluate the perception and usage of the technologies installed via three complementary methods in the next phase of this project (part B):

- Focus Groups: Two or three focus groups with 6-8 participants to evaluate the user perception of the various technologies for different populations.
- Participant Experiments: This evaluation will consider usability, conformance, unsafe behaviors such as jaywalking, and overall satisfaction of the subjects with the app.

- Survey: A survey of the broader Gainesville community, which will examine attitudes regarding the new technology, usability, safety concerns, and other issues.

To support these three methods, the research team has started an Institutional Review (IRB) application, which is a requirement for research involving human participants. The IRB reviews the project applications to determine if the research project follows the ethical principles and regulations for the protection of human subjects. This would allow for behavioral evaluation through focus groups and surveys.

7 "After" Data Collection for Network Performance

In this chapter the research team has developed a system to automate the process of calculating performance measures that are identified in the "before" data collection.

The HCS files developed as part of "before" data collection from the following signalized intersections were used to setup an automated system for evaluation.

- W Univ. Ave. & 13th St.
- W Univ. Ave. & 17th St.
- W Univ. Ave. & Gale Lemerand Dr.

This system was later expanded to include seven intersections to facilitate analysis for Gainesville Trapezium Network (BDV31-977-117). Efforts/resources from this project and the Gainesville Trapezium *(55)* were both used to develop this automated system.

Figure below shows the flowchart for executing this automated system. The steps of the process are as follows. Given the intersections, dates, and time intervals of interest, a Python script automatically downloads high-resolution controller logs containing raw detector data from Amazon Web Services (AWS) storage for the requested dates and times. Each analysis period is divided into 15-minute intervals. The same Python script then processes the detector activations from controller logs. With the help of detector channel mapping accomplished previously for each intersection, the script computes the turning movement counts (TMC) for the study approaches. After the end of this step, the process provides a set of TMCs for each approach and time interval and for the selected dates. The Python script then aggregates the counts by computing their averages for each intersection and each time interval and finally outputs these average counts in a comma-separated values (CSV) file. Next, a PowerShell script processes the turning movement counts in the CSV file and generates an XML file that is used as input to HCS. Finally, the HCS runs in command-line mode, and a second Python script obtains the HCS output to extract the required information. For this report, the required information is the intersection delay for AM, PM, and off-peak periods for all subject intersections.

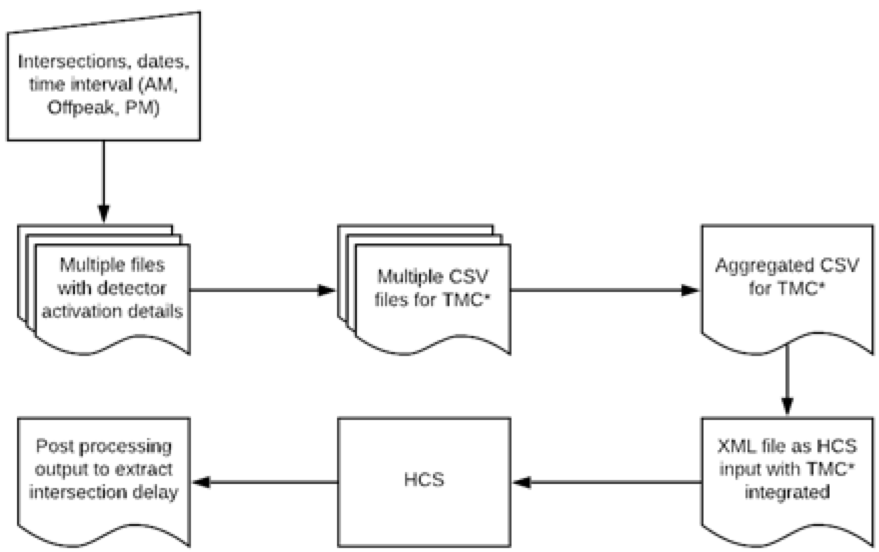


Figure 19 Flowchart showing the automation process (TMC= Turning Movement Counts) (Source[1]: Final Report BDV31-977-117)

This system will enable for accurate evaluation of the study area over multiple time periods during “After study” as part of the next phase of evaluation (Part B). It is to be noted that the study network has undergone changes including creation of new one-way streets and bicyclist paths, decrease in speed limits and introduction of speed tables. These changes need to be updated in the HCS files for an accurate “after” analysis.

For safety data, videos obtained from the fisheye cameras installed from this project (Figure 20) will be used and the video processing techniques developed by UFTI researchers *(56, 57)* will be applied to obtain near-misses.

File: 023_07_2021-11-11_09-30_72111110930232_72111110930234.mp4

intersection_id	5060
camera_id	7
timestamp	2021-11-11 09:32:23.800
dow	3
hod	9
frame_id	1414
conflict_x	349.316
conflict_y	306.311
unique_ID1	72111110930232
unique_ID2	72111110930234
class1	car
class2	pedestrian
phase1	6
phase2	4
time	0.566925
bb_time	0.334961
ttc_rank	0.907571
p2v	1
city	Gainesville
state	FL
cluster1	NBT_lane1
cluster2	ped_WE
is_conflicting	1
speed1	24.1624
speed2	6.37072
distance	3.53473
bb_distance	0.496471
deceleration1	11.1873
deceleration2	4.3509
decel1_ts	2021-11-11 09:32:23.900
decel2_ts	2021-11-11 09:32:24.100

Figure 20 Near miss detection using fisheye camera. Example at Univ. Ave./13th St. intersection

8 Hardware and Software Platform

The research team worked with other UFTI researchers via FDOT funded research in assembling, storing, and analyzing large databases from existing sources.

The research team coordinated with FDOT project BDV31-562-01 (Big Data Management Pilot). This project describes a three-tiered architecture consisting of edge, local servers, and cloud-based components that can be used to deploy applications. Sensors, data sources, the data ingestion methods, and the core applications are developed and explained in detail.

The “before” data from this project has been stored and processed according to the protocols developed from the Big Data Management project *(58)* explained in the previous paragraph. The principles developed under this project, will be adopted in the next phase of the project (part B).

9 Conclusions

- The "before" analysis highlights key findings such as frequent jaywalking on West University Avenue, reduced jaywalking with the presence of a pedestrian/bicyclist tunnel under 13th Street, and high pedestrian density around bus stops near the Reitz Student Union building.

- The safety analysis examines pedestrian and bicyclist crashes, revealing patterns such as higher numbers of pedestrian crashes on Tuesdays and Fridays, with a concentration of late-night crashes along West University Avenue.

- The mobility study analyzes highway capacity and operational performance at selected intersections, with one unsignalized intersection showing the highest number of crashes.

- To enable an effective evaluation in the next phase, the research team has taken actions such as initiating Institutional Review Board (IRB) application, developing automated performance calculation systems, establishing data storage and processing protocols.

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Appendix A

Field Observations of the Signalized Intersections in the Study Network

<u>S1: (</u><u>Stadium Rd. & Gale Lemerand Dr.)</u>

Figure A1 Stadium Rd. & Gale Lemerand Dr.

<u>Observations:</u>

- Push buttons were available for all approaches

- Higher traffic volume was observed in the NB and SB
- Pedestrians do not adhere to pedestrian signals and cross during red time
    - Frequent jaywalking was seen around this intersection

<u>**S2:** (W Univ. Ave. & 20th Terr. (Gale Lemerand Dr.))</u>

Figure A2 W Univ. Ave. & 20th Terr. (Gale Lemerand Dr.)

<u>Observations:</u>

- 3-legged intersection
- Cars turning right onto W Univ. Ave. stop on crosswalk rather than behind
    - Large brick UF sign and flowerbed obstructs motorists' view of vehicles traveling EB.
- Cycle failure was observed for the EB direction

*W Univ. Ave. sees rampant jaywalking. Crosswalks are only located at signalized intersections, which are too far apart from each other.

<u>**S3:** (W Univ. Ave. & 18th St.)</u>

Figure A3 W Univ. Ave. & 18th St.

<u>Observations:</u>

- Push buttons are available
- Intersection did not experience any cycle failure
- Jaywalking was observed around the intersection
- Some pedestrians/bicyclists do not comply with the signal

S4: (W Univ. Ave. & 17th St.)

Figure A4 W Univ. Ave. & 17th St.

Observations:

- Push buttons are available
- No cycle failure was observed
- Very busy intersection for pedestrians crossing W University Ave.
- Moderate traffic/pedestrian volumes were observed
- It has a bus stop before crossing the signal

S5: (W Univ. Ave. & 15th St.)

Figure A5 W Univ. Ave. & 15th St.)

Observations:

- 3-legged intersection
- Walk signal for pedestrian crossing W University took too long to appear, probably due to high vehicular traffic
- Very busy for pedestrians

<u>S6:</u> <u>(W Univ. Ave. & 13th St.)</u>

Figure A6 W Univ. Ave. & 13th St.

<u>Observations:</u>

- Push buttons are available
- High traffic/pedestrian volume
- Might have sight distance problem due to a building in the corner for SB right turning traffic.

S7: (SW 2 Ave. & 13th St.)

Figure A7 SW 2 Ave. & 13th St.

Observations:

- Traffic sometimes backs up and blocks the intersection/vehicles waiting in the box
- No bike lanes – bicyclists use vehicle lanes coming out of campus
- Left and right turning cars get too close to pedestrians crossing the street
- Right turn vehicles block signal view for the pedestrian/bicyclist
- Cycle failure occurred

S8: (SW 4th Ave. & 13th St.)

Figure A8 SW 4th Ave. & 13th St.

Observations:

- This intersection has three adjacent crosswalks crossing 13th Street
- Traffic backs up in the middle of the intersection during the peak hour
- Some pushbuttons have auditory signals and some do not

S9: (SW 5th Ave. & 13th St.)

Figure A9 SW 5th Ave. & 13th St.

Observations:

- Underground pedestrian tunnel available south of the intersection
- Intersection also experiences cycle failure during peak hour
- Pedestrian signals on the northern side takes too long to appear
- Queue length has crossed the adjacent intersection

<u>S10:</u> <u>(SW 8th Ave. & 13th St.)</u>

Figure A10 SW 8th Ave. & 13th St.

<u>Observations:</u>

- Tree may block vehicles' view of pedestrian/bicyclists
- Dedicated right turn lane coming from Museum Rd

S11: (Museum Rd. & Newell Dr.)

Figure A11 Museum Rd. & Newell Dr.

Observations:

- A couple of instances of jaywalking were observed

S12: (Museum Rd. & Center Dr.)

Figure A12 Museum Rd. & Center Dr.

Observations:

- A couple of instances of jaywalking were observed
- Pedestrians frequently cross intersection when signal is red

S13: (Museum Rd. & Gale Lemerand Dr.)

Figure A13 Museum Rd. & Gale Lemerand Dr.

Observations:

- Observed a near-collision: bicyclist overshoots end of bike lane on Museum Road going WB and almost broadsides a white SUV turning right on Gale Lemerand Drive.

Appendix B

Field Observations of the Mid-block Crossings in the Study Network

<u>C1:</u>

Figure B1 Mid-block crossing to the east side of O'Connell Center on Gale Lemerand Drive

<u>Observations:</u>

- No flashing beacons
- Trees in the area may affect sight distance – obstructs drivers' view of pedestrians
- Traffic separator is available to act as a pedestrian island
- Triangular sign ahead of the mid-block crossing

<u>C2:</u>

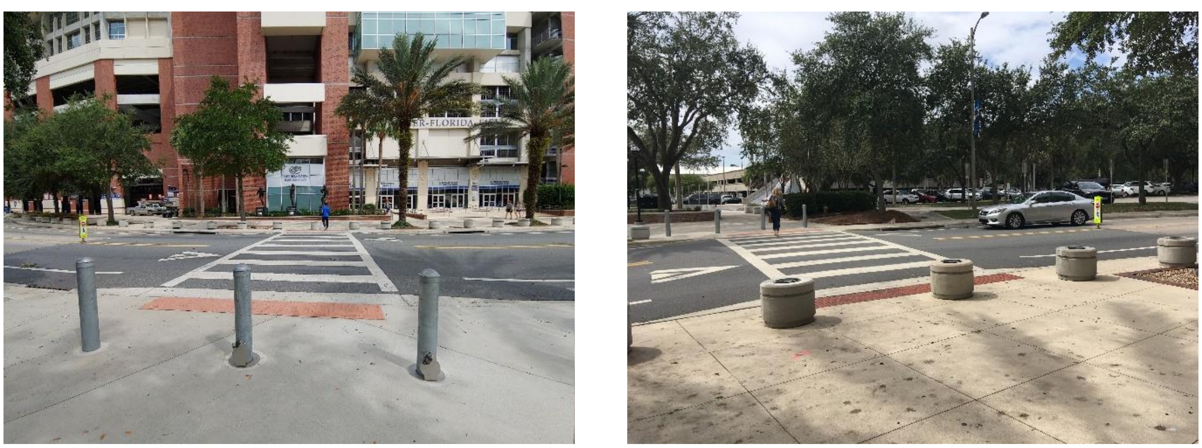


Figure B2 Mid-block crossing to the north side of O'Connell Center on Gale Lemerand Drive

Observations:

- Undivided roadway
- No yellow pedestrian crossing warning sign at the mid-block crossing
- Rectangular "Yield to Pedestrians" sign between the double yellow line

C3:


Figure B3 Mid-block crossing to the east of ChargePoint charging station on Gale Lemerand Drive

Observations:

- Yellow warning sign on sidewalk at the mid-block crossing (NB direction)
- Shortest mid-block crossing on this part of the corridor
- No flashing beacons

C4:


Figure B4 Mid-block crossing to the northwest corner of Stadium on Gale Lemerand Drive

Observations:

- No rectangular warning signs at the mid-block crossing, only yellow signs ahead.
- Large tree on the NB side may obstruct view of pedestrians for vehicles heading SB

C5:

Figure B5 Mid-block crossing in front of Beaty Towers

Observations:

- Speed bumps in front of the mid-block crossing to slow down vehicles
- Rectangular "Yield to Peds" sign around the mid-block crossing
- It has a flashing beacon attached to warning sign
- Traffic separator also acts as a pedestrian island

C6:

Figure B6 Unsignalized intersection at Museum Rd. & Reitz Union Dr.

Observations:

- This operates as a two-way stop-controlled T intersection
- Very high volume of pedestrians
- Long queues created by frequent stopping for pedestrians
- Has rectangular yield to peds signs but no yellow diamond warning signs
- Cars coming out of Reitz Union often stop on the cross walk, and the façade of the building obstructs their view of cars going west

C7:

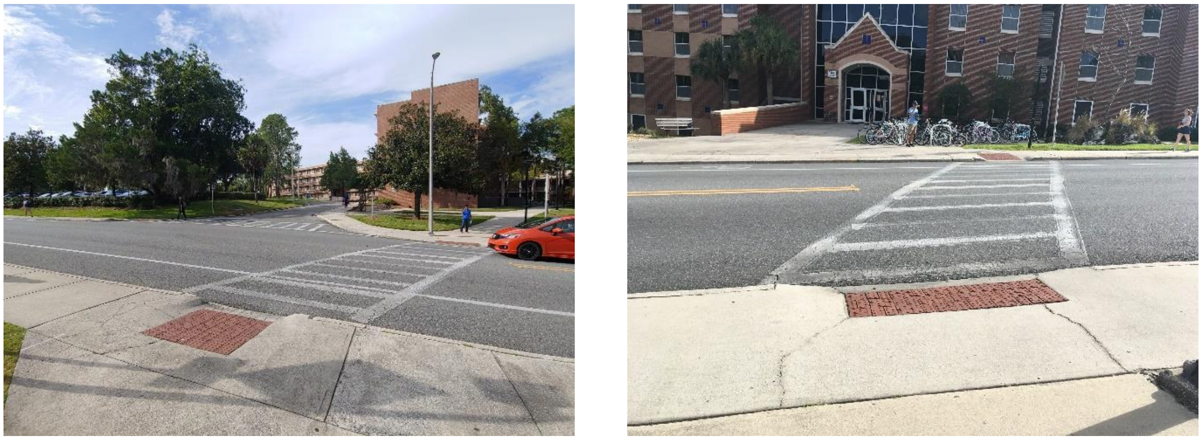


Figure B7 Mid-block crossing at Hume Hall East

Observations:

- Crest curve SSD could obstruct view of pedestrians for drivers going EB.
    - Dim lighting on this road could exacerbate this issue during nighttime.
- Yellow warning signs at the mid-block crossing
- Sun glare may affect drivers' view towards the WB

C8:

Figure B8 Mid-block crossing at Hume Hall Common Building

Observations:

- Crest curve SSD could be an issue for drivers going WB
    - Could be a bigger problem at night
- Yellow warning signs at the mid-block crossing
- Bus stop before mid-block crossing, the shed of the stop may obstruct view of warning sign

C9:

Figure B9 Mid-block crossing at Graham Hall

Observations:

- It has flashing beacons
- Traffic separating median/island
- Rectangular yield to pedestrians sign

C10:

Figure B10 Mid-block crossing to the west of FICS lab on Gale Lemerand Drive

Observations:

- Yellow warning signs
- Horizontal curvature of the roadway could cause SSD issues for vehicles traveling NB

<u>C11:</u>

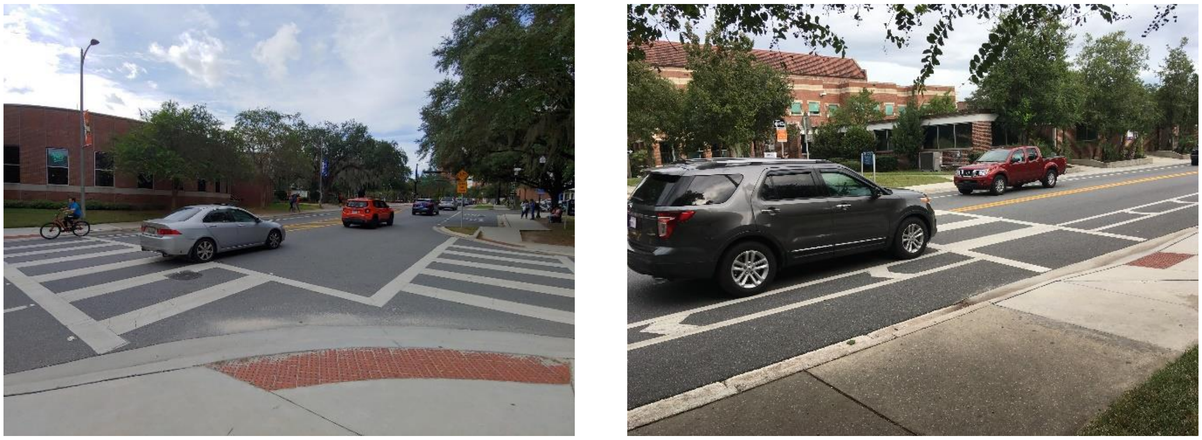


Figure B11 Mid-block crossing to the east of Gator Dining on Gale Lemerand Drive

<u>Observations:</u>

- Has yellow warning signs
- It is located a bit too close to the intersection up ahead, could cause traffic to back up during high volumes due to stopping for pedestrians
- Drivers going south may be less acclimated to stop soon after clearing the intersection.

Table B1 Score assigned for each of the features of mid-block crossings

Features	Assigned score
Number of warning signage	"2"= 1, "3"= 0.5, "4 or 5"= 0
Type of warning signage	N/A
Distance of signs from crossing	10 ft = 1, > 25 ft = 0
Presence of median	Y = 0, N = 1
Bus stop near mid-block crossing	Y = 0, N = 1
Obstructions (SSD, trees, etc.)	Obstruction = 1, No Obstruction = 0

Appendix C

Distribution of Crashes along the Corridors

1) Gale Lemerand Drive:

Table C1 Total crashes (pedestrian & bicycle) along Gale Lemerand Drive

	Pedestrian	Bicycle
No of Crashes	9	8

A. Pedestrian Crashes:

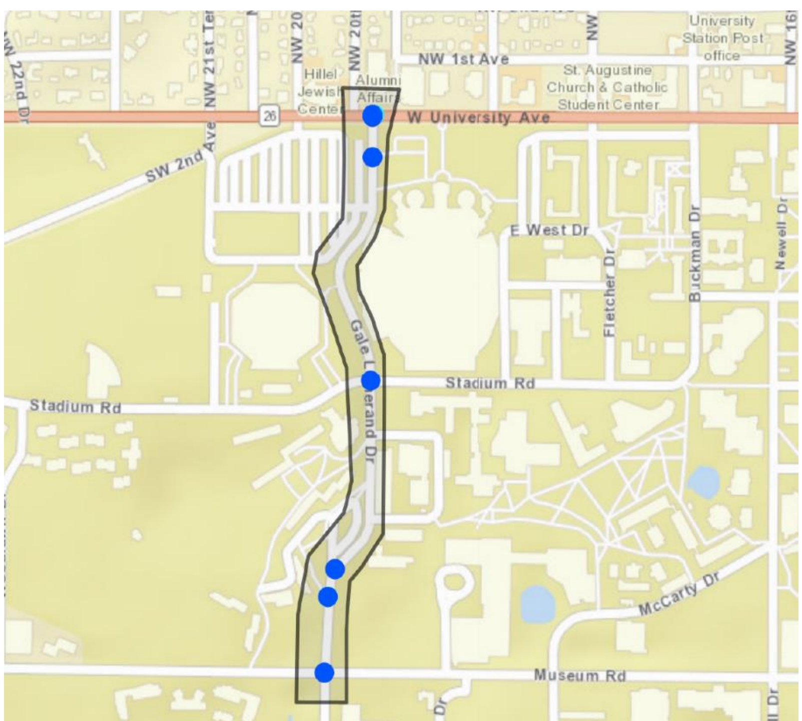


Figure C1 Distribution of pedestrian crashes by location - Gale Lemerand Drive

Pedestrian Intersection Crashes at Gale Lemerand Drive

The intersection of Gale Lemerand and Museum Road is one of the busiest intersections in the campus. This intersection is connected to the Reitz Union/ UF bookstore in the West, W. University Avenue in the North, Archer road in the South and the Student Recreation Center and dorms in the East direction. Pedestrians cross from all directions heading to the Reitz Union. The number of pedestrians will likely increase in the near future because of a new five-floor garage on the southwest corner of this intersection. This intersection has one pedestrian crash in the last five years. The cause of the crash was aggressive behavior of a motorcycle driver who hit the law enforcement office when he tried to stop him at the intersection.

Gale Lemerand Dr. & Museum Road

Gale Lemerand Dr. Mid-Block Crossing

Gale Lemerand Dr. & Stadium Road

Gale Lemerand Dr. & W University Ave

Figure C2 Locations of pedestrian crashes along Gale Lemerand Drive

The pedestrian crossings on Gale Lemerand Dr. have three pedestrian crashes. In all three crashes the driver was at fault where the vehicle failed to yield at the crosswalk. All three crashes were the result of inattention and careless driving.

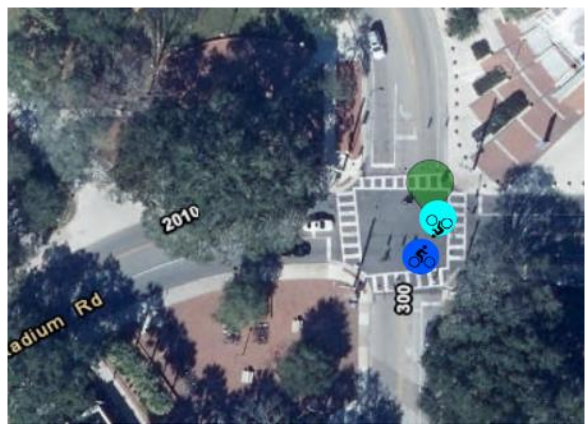
Table C2 Gale Lemerand Drive pedestrian crashes

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
Gale Lemerand & Museum	Argument	Hit law enforcement officer	Aggressive behavior		Traffic lights	Driver	At intersection	Unknown	Law enforcement officer asked motorcycle driver to turn SB on Gale Lemerand. V1 hit law enforcement officer and fled
Gale Lemerand Mid-Block Crossing	Failed to yield for ped	Hit pedestrian	Inattention		None	Driver	At Crosswalk	Straight	
Gale Lemerand Mid-Block Crossing	Failed to yield for ped	Hit pedestrian	Inattention		None	Driver	At Crosswalk	Straight	
Gale Lemerand Mid-Block Crossing	v2 hit rear end by v1	v2 hit ped	Inattention	careless driving	None	Driver	At Crosswalk	Straight	Vehicle 2 stopped at crosswalk for ped crossing hit from rear by V1. V2 hit ped. V1 was driving with suspended license
Gale Lemerand & Stadium Road	failed to yield for Ped	hit pedestrian	ped not seen		green for Bus	Driver	At Crosswalk	Left Turn on Gale lemerand	Bus was trying to take left on Gale Lemerand from Stadium when it had green it took left turn and did not see ped. Hit ped.
Gale Lemerand & W. University Avenue	Hit Pedestrian		Inattention	failed to yield for pedestrian	traffic signal	Driver	At Crosswalk	Right Turn	Vehicle hit ped while making right turn on red signal. Confusion with walk signal
Gale Lemerand & W. University Avenue	Hit Pedestrian		Inattention	failed to yield for pedestrian	traffic signal	Driver	At Crosswalk	Right Turn	Vehicle hit ped while making right turn on red signal. Confusion with walk signal
Gale Lemerand & W. University Avenue	Hit Pedestrian		Failed to yield for pedestrian		none	driver	not at crosswalk	Straight	Vehicle hit pedestrian on Gale Lemerand Dr. away from intersection
Gale Lemerand & W. University Avenue	Hit Pedestrian		Ran in front of vehicle	failed to yield for vehicle	green traffic signal	pedestrian	at crosswalk	Straight	Pedestrian ran in front of vehicle and got hit by vehicle

B. Bicycle Crashes:

Figure C3 Distribution of bicycle crashes by location- Gale Lemerand Drive

Gale Lemerand Dr. & Museum Road



Gale Lemerand Dr. & Stadium Road

Gale Lemerand Dr. & West University Avenue

Figure C4 Location of bicycle crashes along Gale Lemerand Drive

Table C3 Gale Lemerand Drive bicycle crashes

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
Gale Lemerand & Museum	lost control	Hit v1 rear windshield	lost control			None	Parking lot	none	Bicyclist lost control near legally parked vehicle and hit rear windshield
Gale Lemerand & Museum	Failed to yield for v1	Hit v1	ran red light		red light for bicycle	Bicyclist	At Intersection	straight	
Gale Lemerand & Stadium Road	v1 turning right	side swipe to bicyclist	failed to see bicyclist	improper right turn	Green light	Driver	At Intersection	right	V1 was traveling southbound on Gale Lemerand was turning right on Stadium Road and hit bicyclist in bike lane
Gale Lemerand & Stadium Road	P1 opened door while v1 stopped	door side swipe to bicyclist	failed to see bicyclist	improper gate open	none	Passenger	Not at Intersection	standing	
Gale Lemerand & W.Univesity Av.	pulled in front of V1	Hit Bicyclist	inattention	Failed to yield for pedestrian	Green walk light	Driver	At Crosswalk	right turn	Vehicle failed to yield for bicyclist while making right turn when walk light was green
Gale Lemerand & W.Univesity Av.	pulled in front of V2	Hit Bicyclist	Failed to yield for vehicle		Green traffic light	Bicyclist	At Crosswalk	right turn	Bicyclist failed to yield for vehicle turning right
Gale Lemerand & W.Univesity Av.	pulled in front of V3	Hit Bicyclist	Failed to yield for vehicle	D1 right view obstructed	Green traffic light	Bicyclist	At Crosswalk	right turn	Bicyclist pulled in front of v1 from side of standing pedestrian
Gale Lemerand & W.Univesity Av.	pulled in front of V4	Hit Bicyclist	Failed to yield for vehicle	confusion in traffic light	Red walk light	Bicyclist	At Crosswalk	right turn	Bicyclist trying to cross W University Avenue hit by right turning v1

2) West University Avenue:

Table C4 Total crashes (pedestrian & bicycle) along West University Avenue

	Pedestrian	Bicycle
No of Crashes	27	26

A. Pedestrian Crashes

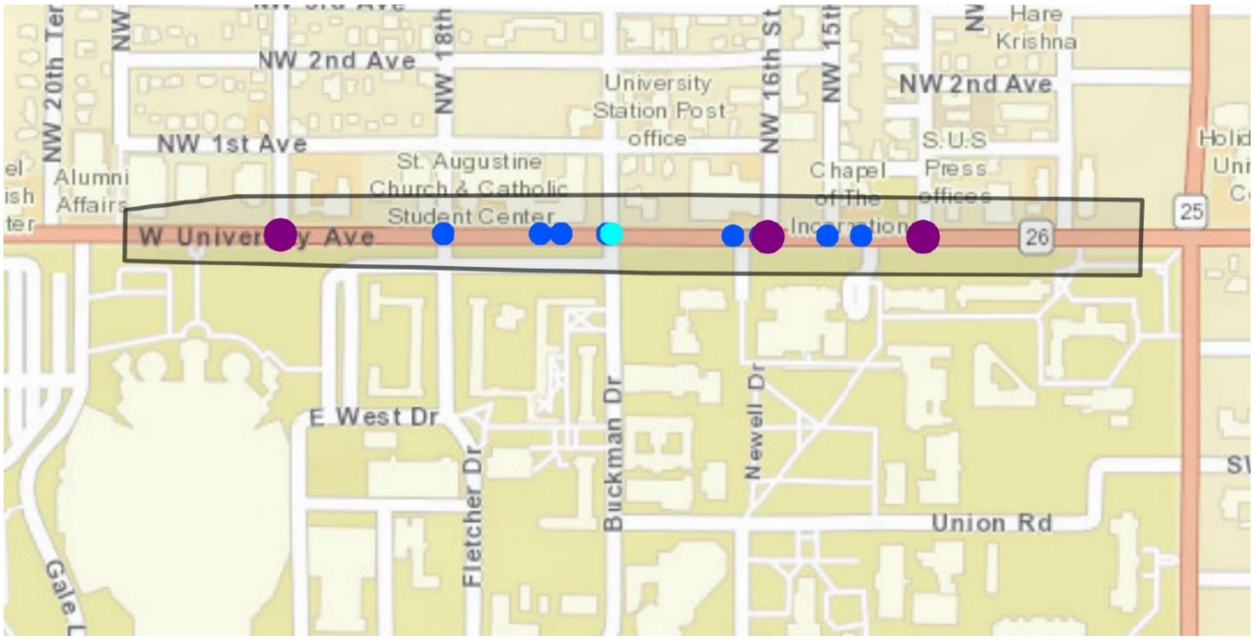


Figure C5 Distribution of Pedestrian crashes by Location- West University Avenue

W. University Ave & 19th St

W. University Ave & 18th St & Fletcher Dr.

W. University Ave & 17th St & Buckman Dr.

W. University Ave & NW 16th St

W. University Ave & NW15th Terr.

W. University Ave & NW 15th St

W. University Ave & NW 13th St

Figure C6 Location of pedestrian crashes along West University Avenue

Table C5 Pedestrian crashes- West University Avenue

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
W. Univesity & 19th Street	Ran in front of V1	HIT PEDESTRIAN	INATTENTION	DECISION	green traffic light	PEDESTRIAN	NOT AT CROSS WALK	straight to W. Univ. Ave.	P1 crossing W. University Ave. Hit by west bound V1
W. Univesity & 19th Street	failed to yield for V1	HIT PEDESTRIAN	POOR LIGHTS	DARK	TRAFFIC LIGHTS	PEDESTRIAN	at cross walk	left turn to 19th st	D1 did not see p1 while turning left due to poor lights and black clothes worn by P1
W. Univesity & 18th Street	Ran in front of v1	hit pedestrian	failed to yield for red walk sign	failed to yield for V1	red walk sign	pedestrian	at crosswalk	turning left on W. Univ. Ave.	V1 turning left on W University hit P1 who failed to stop at red walk sign
W. University & 18th Street	ran in front of V1	hit pedestrian	failed to yield for red walk sign	failed to yield for V1	red walk sign	pedestrian	at crosswalk	straight	V1 had green light and P1 failed to yield for V1 and hit him
W. Univesity Av & 17th Street	Hit Pedestrian		Inattention	failed to Stop at Red light	red light	Driver	at crosswalk	left turn	Pedestrian hit by vehicle
	hit stopped car	Hit Pedestrian	careless driving	lost control	traffic light	Driver	not at crosswalk	straight	Pedestrian hit by vehicle
	Hit Pedestrian		Decision error		red walk sign	Pedestrian	at crosswalk	straight	Pedestrian hit by vehicle
	Hit Pedestrian		Inattention	failed to yield no walk sign	red walk sign	Pedestrian	at crosswalk	straight	Pedestrian hit by vehicle
	Hit Pedestrian		Inattention	ran in front of vehicle	no	Pedestrian	not at crosswalk	straight	Pedestrian hit by vehicle
	Hit Pedestrian		Inattention	ran in front of vehicle	no	Pedestrian	not at crosswalk	straight	Pedestrian hit by vehicle
	Hit Pedestrian		decision error	failed to yield for traffic light	traffic light	Pedestrian	at crosswalk	straight	Pedestrian hit by vehicle
W. University Avenue & 16th Street			DUI	Failed to yield for V1		Pedestrian	Not at cross walk	straight	
			In attentive driving			D1	no cross walk	turning left	D1 driving carelessly and failed to see P1
			DUI	Failed to yield for V1		Pedestrian	not at cross walk	straight	P1 ran in front of v1 . No cross walk present
			failed to yield for V1		NO	Pedestrian	No at cross walk	straight	P1 ran from front of the stopped bus
W. Univesity & 15th Terr.			DUI			Pedestrian	crosswalk	straight	P1 fell in front of v1
			d1 failed to yield			D1	NOT AT CROSSWALK	stright	
W. Univesity & 15th Street			Traffic Signal Issue		Green for vehicle	none	crosswalk	v1 turning left	Signal problem both walk sign and left green at same time

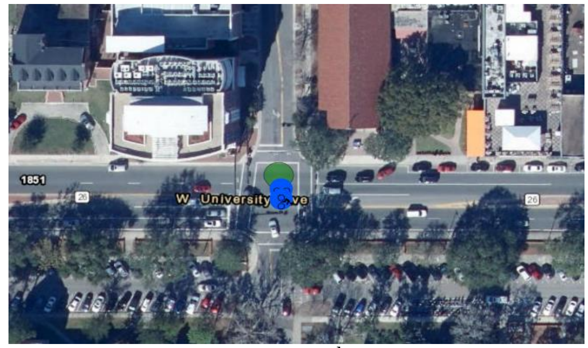
Table C5 Continued

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
			D1 failed to yield for Ped		Green for Vehicle	DRIVER	crosswalk	v1 turning left	
			D1 failed to yield for Ped		Green for Vehicle	Driver	crosswalk	v1 turning left	
			D1 failed to stop at red light		Red light for vehicle	Driver	crosswalk	V1 going straight	Signal confusion
	ran in front of vehicle	Hit pedestrian	view obstructed by bus	failed to see Pedestrian	red walk sign	Pedestrian	at crosswalk	straight	V1 view was obstructed by bus on left turn lane when ped pulled in front of V1
	ran in front of vehicle	Hit pedestrian	Failed to Yield		red walk sign	Pedestrian	at crosswalk	straight	
W. Univesity & SW. 13th Street	Failed to yield for pedestrian	Hit pedestrian	failed to stop for red light		RED TRAFFIC LIGHT	Driver	at crosswalk	straight	
	Failed to yield for pedestrian	Hit pedestrian	DUI	Not crossing at crosswalk	no traffic lights	Driver/Pedestri an	not at crosswalk	straight	
	ran in front of vehicle	Hit pedestrian	Alcohol		red walk sign	Pedestrian	at crosswalk	left turn	
W. Univesity & SW. 13th Street	ran in front of vehicle	Hit pedestrian	inattention		no traffic lights	Pedestrian	not at crosswalk	straight	

B. Bicycle Crashes:

Figure C7 Distribution of Bicycle crashes by Location- West University Avenue

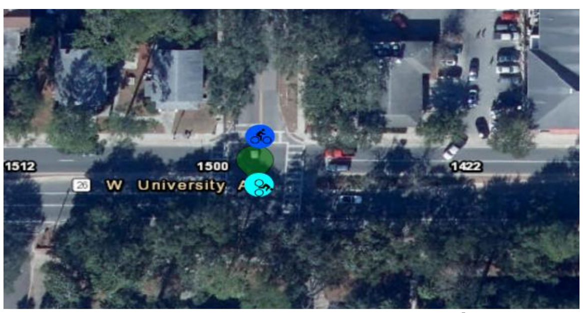
W. University Ave & 19th St



W. University Ave & 18th St & Fletcher Dr.

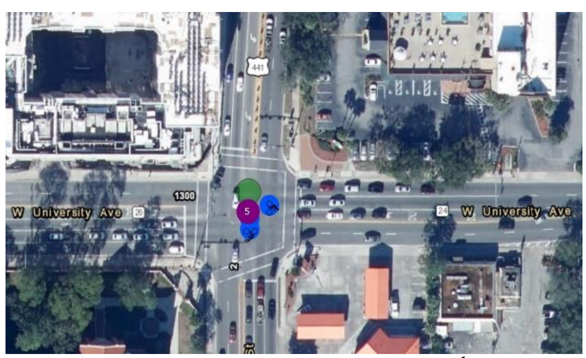
W. University Ave & 17th St & Buckman Dr.

W. University Ave & NW 16th St



W. University Ave & NW 15th Terr.

W. University Ave & NW 14th St



W. University Ave & NW 13th St

Figure C8 Location of bicycle crashes along West University Avenue

Table C6 Bicycle crashes-West University Avenue

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
W. Univesity & 19th Street	ran in front of vehicle	hit bicyclist	inattention	failed to yield for Bicyclist	none	Bicyclist	At intersection	straight	
W. Univesity & 19th Street	backing up vehicle in parking lot	hit bicyclist	inattention	failed to see Bicyclist	none	v1 driver	In parking lot	parked	No citation issued since crash was reported late
W. Univesity & 18th Street	ran in front of v1	hit bicyclist	no lights on bicycle	failed to see bicyclist	none	Ped	Not at crosswalk	left	
W. Univesity & 18th Street	hit bicycle		failed to see bicycle		stop sign	v1 driver	At Crosswalk	right	V1 did not see bicycle and hit it on crosswalk.
W. Univesity & 18th Street	ran in front of v1	hit bicyclist	failed to see bicycle		traffic light	v1 driver	At Crosswalk	right	D1 had suspended license and failed to see bicyclist who suddenly pulled in front of v1
W. Univesity & 17th Street	Hit Bicyclist		Failed to Yield traffic light	confusion in traffic light	traffic light	driver	At Crosswalk	turning right	
W. Univesity & 17th Street	Hit Bicyclist		other vehicle	swerve away from vehicle	traffic light	none	At Crosswalk	turning left	
W. Univesity & 17th Street	Hit Bicyclist		DUI	DRUGS	traffic lights	Bicyclist	At Crosswalk	turning right	
W. Univesity & 17th Street	Hit Bicyclist		bicycling in travel lane	side swipe	none	Bicyclist	In Travel Lane	straight	
W. Univesity & 16th Street	Bicycle ran in front of motorcycle	hit bicyclist	right turn blinker on by motorcycle	failed to yield for bicyclist	none	v1 driver	Not on crosswalk	straight	V1 motorcycle had right turn blinker on which confused the bicyclist and he ran in front of motorcycle
W. Univesity & 16th Street	failed to yield for bicyclist	hit bicyclist	failed to see Bicyclist		stop sign	v1 driver	At Crosswalk	right	
W. Univesity & 16th Street	changed lane	hit bicyclist	confusion		none	v1 driver	Not on crosswalk	straight	
W. Univesity & 15th Street	ran in front of vehicle	hit bicyclist	failed to see bicyclist	failed to yield for bicyclist	red traffic light	v1 driver	At Intersection	right	
W. Univesity & 15th Street	failed to yield for Bicyclist	hit bicyclist	ran red light		red traffic light	v1 driver	At Intersection	straight	
W. Univesity & 14th Street	failed to yield for Bicyclist	hit bicyclist	inattention	failed to see bicyclist	stop sign	v1 driver	At intersection / crosswalk	left	At the time of crash the median was open to make left turn

Table C6 Continued

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
W. University & 14th Street	failed to yield for Bicyclist	hit bicyclist	vision obscured by semi truck in outer lane	failed to see bicyclist	stop sign	bicyclist		straight	
W. Univesity & 14th Street	failed to yield for Bicyclist	hit bicyclist	inattention		stop sign	v1 driver		right	
W. Univesity & 14th Street	ran red walk sign	hit bicyclist	ran red walk sign		red walk sign	bicyclist		straight	
W. Univesity & SW. 13th Street	right turn without vehicle right light on	hit bicyclist	confusion	failed to yield	red traffic light	V1 driver	at intersection	right	V1 turned right on 13th without having right turn blinkers on. Bicyclist thought he is going straight.
W. Univesity & SW. 13th Street	failed to yield	hit bicyclist	Inattention	failed to yield	red traffic light	v1 driver	at intersection	right	
W. Univesity & SW. 13th Street	ran red walk sign	hit bicyclist	Inattention	failed to yield for vehicle	red walk light	bicyclist	at intersection	straight	
W. Univesity & SW. 13th Street	right turn on red	hit bicyclist	Inattention	failed to yield on green walk sign	green walk light	V1 driver	at intersection	right	
W. Univesity & SW. 13th Street	right turn on red	hit bicyclist	Inattention	failed to yield on green walk sign	green walk light	V1 driver	at intersection	right	
W. Univesity & SW. 13th Street	right turn on red	hit bicyclist	inattention/ sun glare	failed to yield on green walk sign	green walk light	V1 driver	at intersection	right	
W. Univesity & SW. 13th Street	right turn on red	hit bicyclist	Inattention	failed to yield for green walk sign	green walk light	v1 driver	at intersection	right	
W. Univesity & SW. 13th Street	right turn on red	hit bicyclist	Inattention	failed to yield for green walk sign	green walk light	V1 driver	at intersection	right	

3) 13th Street:

Table C7 Total crashes (pedestrian & bicycle) along 13th Street

	Pedestrian	Bicycle
No of Crashes	3	7

A. Pedestrian Crashes

Figure C9 Distribution of pedestrian crashes by location - 13th Street

NW13th St. & SW 2nd Av

NW13th St. & Museum Road

Figure C10 Locations of pedestrian crashes along 13th Street

Table C8 Pedestrian crashes- 13th Street

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
SW. 13th St. & 2nd Av	failed to yield for Ped	hit pedestrian	Stress	failed to yield for Pedestrian	Traffic lights	driver	at crosswalk	straight	V1 failed to yield for ped. V1 husband was admitted in ER and was little stressed. She didn't realize she has hit a ped and said she thought she had hit a dog.
SW. 13th St. & 2nd Av	ran in front of v1	hit pedestrian	inattention	careless	Traffic lights	pedestrian	at crosswalk	straight	Ped ran in front of v1 and was hit by v1
SW. 13th St. & Museum Road	failed to yield for ped	hit pedestrian	Blocked line of sight due to vehicle ahead	failed to see ped	flashing yellow to turn left	driver	at crosswalk	left turn on sw13th from 8th av	V1 had vehicle ahead and flashing yellow light to turn left on SW 13th St. V1 failed to see ped and hit him

B. Bicycle Crashes:

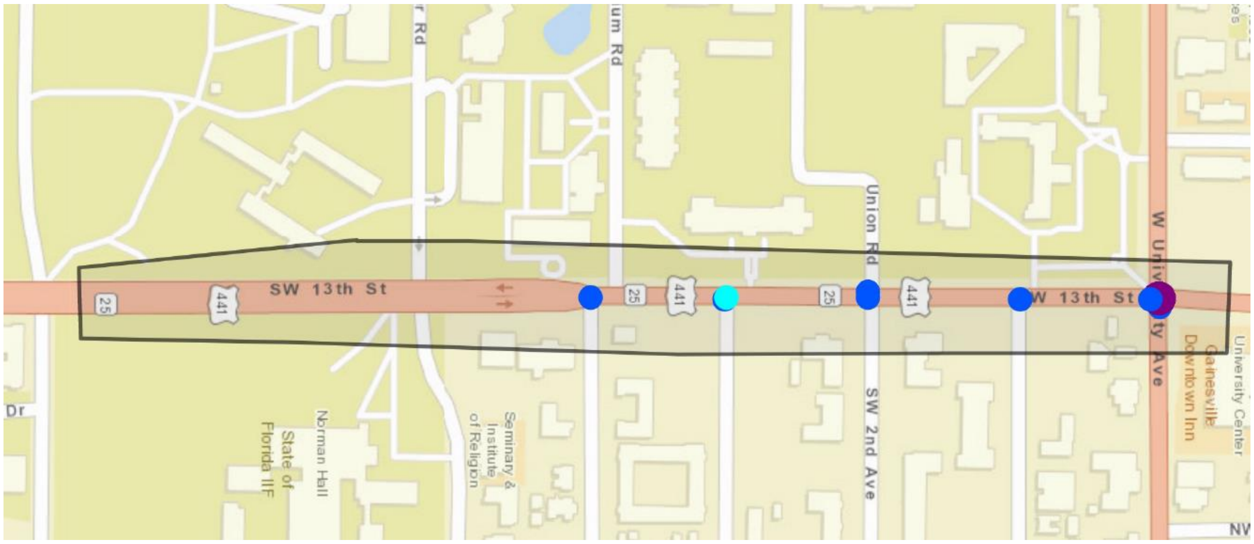
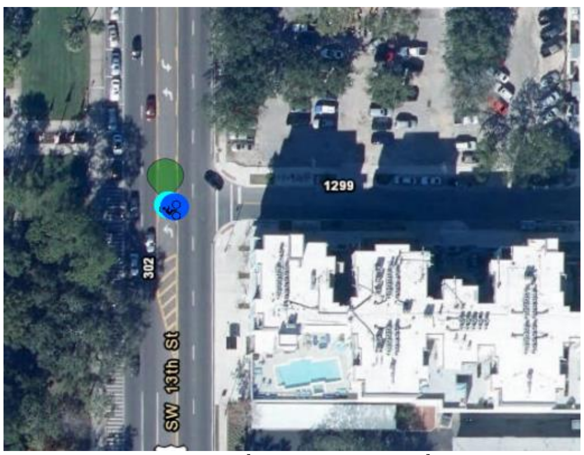


Figure C11 Distribution of bicycle crashes by location- 13th Street

Bicycle Intersection Crash Location- 13th Street

NW13th St. & SW 1st Av.

NW13th St. & SW 2nd Av.



NW13th St. & SW 3rd Av.

W13th St. & SW 4th Av.

NW13th St. & Museum Road

Figure C12 Location of bicycle crashes along 13th Street

Table C9 Bicycle crashes-13th Street

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
SW. 13th St. & 1st Av	right turn from parking lot	hit bicyclist	failed to yield for bicyclist	did not see bicyclist	stop sign	v1 driver	at crosswalk	right	
SW. 13th St. & 2nd Av	ran red light	hit bicyclist in crosswalk	failed to yield for bicyclist	ran red light	red traffic signal	v1 driver	at intersection crosswalk	left	V1 ran red light and hit bicyclist on crosswalk and did not stop.
SW. 13th St. & 2nd Av	entered wrong way	hit bicyclist while pulling out	failed to see bicyclist while backing off	entered wrong way	oneway stop sign	v1 driver	at intersection crosswalk	none	V1 entered the one way street and stopped at the stop sign before the crosswalk and tried to pull out and hit the bicyclist cross the crosswalk. V1 hit the bicyclist who fell down.
SW. 13th St. & 3rd Av	ran stop sign	hit bicyclist	failed to yield for bicyclist	ran stop sign	stop sign	v1 driver	at cross walk	right	
SW. 13th St. & 3rd Av	hit bicyclist		failed to yield for bicyclist		none	v1 driver	at cross walk	left	
SW. 13th St. & 4th Av	improper right turn	hit bicyclist	right turn on red	failed to yield for bicyclist	red traffic light for right turn	v1 driver	at crosswalk	right	V1 ran no right turn on red and hit bicyclist
SW. 13th St. & Museum Road	bicycle in outside lane with unknown vehicle	side swipe with v1	improper lane change	bicyclist failed to see v1	none	bicyclist	not at intersection	straight	Bicyclist was walking with bicycle in outside lane suddenly changed lane and hit v1 right side mirror and fell down.

4) Museum Road:

Table C10 Total crashes (pedestrian & bicycle) along Museum Road

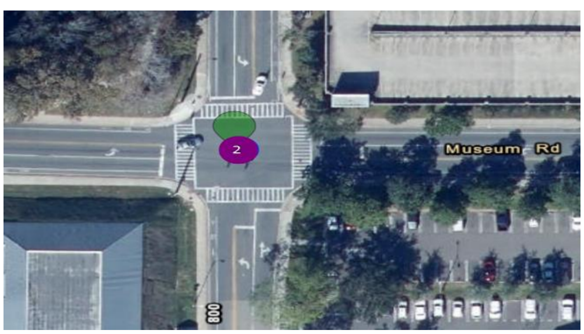
	Pedestrian	**Bicycle**
No of Crashes	10	7

A. Pedestrian Crashes

Figure C13 Distribution of pedestrian crashes by location - Museum Road

Museum Road & Reitz Union Dr.

Museum Road & McCarty Dr.



Museum Road & Newell Dr.

Museum Rd Mid Block crash

Figure C14 Locations of pedestrian crashes along Museum Road

Table C11 Pedestrian crashes- Museum Road

Intersection	First Harmful Event	Second Harmful Event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement	Comment
Museum Road & Reitz Union Dr.	Failed to see Ped	hit pedestrian	Inattention	crowded	no	driver	at cross walk	left turn on Museum road	V1 turned left on museum road and did not see ped. Hit ped
Museum Road & Reitz Union Dr.	Failed to see Ped	hit pedestrian	Glare on windshield		no	driver	at cross walk	straight	V1 going straight had sun glare on wind shield and did not see ped on cross walk. V1 hit ped
Museum Road & McCarthy Dr.	failed to see for skateboard	hit pedestrian on skateboard	inattention		none	driver	at crosswalk away from intersection	straight	V1 stopped at crosswalk to clear and according to her skateboard suddenly came and v1 hit him
Museum Road & McCarthy Dr.	bus failed to see ped	hit pedestrian	Inattention	careless driving	traffic light	driver	at crosswalk	Left on Museum from center dr	V1 making left turn on museum from center drive failed to pedestrian crossing on crosswalk and failed to see him. V1 hit ped
Museum Road & McCarthy Dr.	bus failed to yield for Ped	hit pedestrian	inattention	careless driving	traffic light	driver	at crosswalk	left on center dr from museum	V1 making left on Center Dr. from Museum Road and hit pedestrian crossing museum road
Museum Road & Newell Dr.	failed to yield	hit pedestrian	Failed to see Ped		traffic lights	driver	at cross walk	turn left on museum	Vehicle turning left on museum road from Newell Road and failed to see ped. V1 hit ped.
Museum Road & Newell Dr.	failed to see ped	hit pedestrian	ped on blind spot		traffic lights	ped	at cross walk	left turn on Museum	Ped failed to yield for bus and crossing cross walk on red walk sign
Museum Road-Mid-Block crossing	Failed to yield for Ped	hit pedestrian	speeding		none	driver	at crosswalk	straight	This was football game day and lots of pedestrian were there. Rained heavily before crash but visibility was clear. Area well lit
Museum Road-Mid-Block crossing	Failed to yield for Ped	hit pedestrian	inattention		none	driver	at crosswalk	straight	
Museum Road-Mid-Block crossing	failed to yield for ped	hit pedestrian	failed to see Ped		none	Scooter Driver	at crosswalk	straight	

B. Bicycle Crashes:

Distribution of Bicycle Crashes by Location- Museum Road

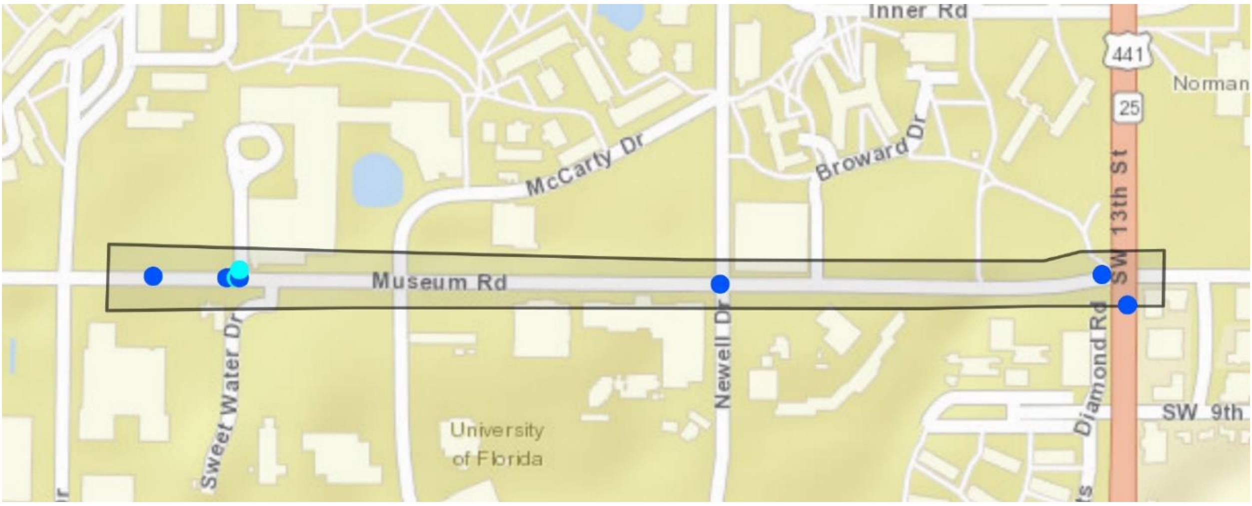
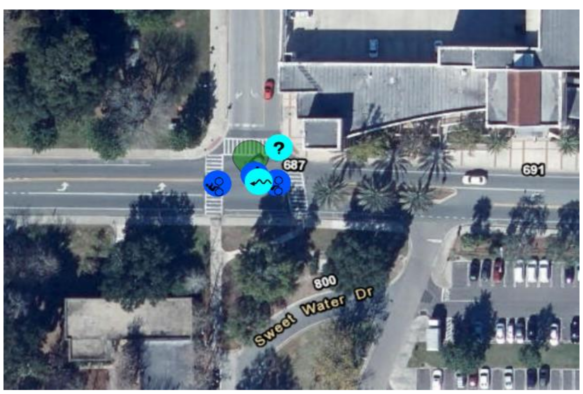
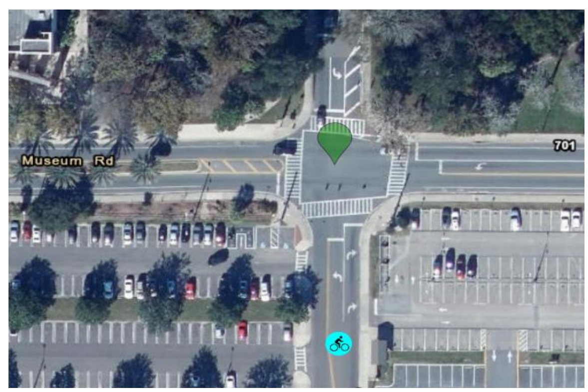


Figure C15 Distribution of bicycle crashes by location- Museum Road



Museum Road & Reitz Union Dr.



Museum Road & McCarty Dr.

Museum Road & Newell Dr.

Figure C16 Location of bicycle crashes in Museum Road

Table C12 Bicycle crashes-Museum Road

Intersection	First Harmful Event	Second Harmful event	Crash Contributing Factor_1	Crash Contributing Factor_2	Traffic Control Device	At Fault	Crash Location	Vehicle Movement
Museum Road & Reitz Union Dr.	left turn	hit bicyclist	failed to yield for bicyclist	improper left turn	stop sign	v1 driver	at intersection	left
Museum Road & Reitz Union Dr.	right turn	hit bicyclist	failed to see bicyclist		stop sign	none	at intersection	right
Museum Road & Reitz Union Dr.	left turn	hit bicyclist	failed to see bicyclist coming	blind spot due to bus next to bike lane	stop sign	v1 driver	at intersection	left
Museum Road & Reitz Union Dr.	hit bicyclist while crossing		failed to see bicyclist		stop sign	v1 driver	at intersection	straight
Museum Road & Reitz Union Dr.	improper left turn	hit bicyclist	failed to see bicyclist	probable site block due to RTS bus	none	motorcycle driver	at intersection	left
Museum Road & McCarthy Dr.	left turn in parking	hit bicyclist	failed to stop for bicyclist	bicyclist too fast to stop	none	none	not at intersection	left
Museum Road & Newell Dr.	ran in front of bus	hit bicyclist	ran red walk light	failed to yield for bus	red walk sign	bicyclist	at intersection	right

Appendix D

Input Data Tables & Results of the Signalized Intersections

1. W Univ. Ave. & 13th St.

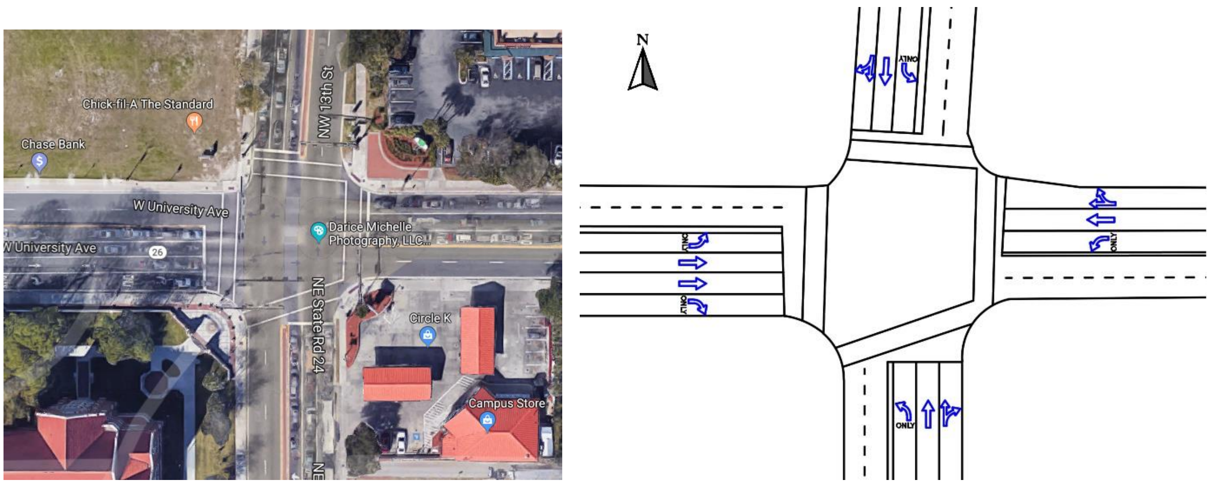


Figure D1: Layout and lane configuration of the intersection W Univ. Ave. & 13th St.

Table D1: Geometric data of the intersection W Univ. Ave. & 13th St.

Geometric Data	EB			WB			NB			SB		
	L	Th	R	L	Th	R	L	Th	R	L	Th	R
Number of lanes	4			3			3			3		
Average lane width (ft)	11			11			11			11		
Number of receiving lanes (ln)	2			2			2			2		
Turn bay length (ft)	450	690	240	240	605	-	310	545	-	470	590	-
Presence of on-street parking	0			0			0			0		
Approach grade (%)	0			0			0			0		
Total walkway width (ft)	10			10			10			10		
Crosswalk width (ft)	10			10			10			10		
Crosswalk length (ft)	70			70			75			70		
Corner radius (ft)	30			30			35			20		

Figure D2: Fisheye camera view of the intersection W Univ. Ave. & 13th St.

Table D2: Traffic characteristics of the intersection W Univ. Ave. & 13th St.(Analysis period 1)

Traffic Characteristics	**EB**			**WB**			**NB**			**SB**		
	L	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	160	356	220	92	340	80	264	610	198	76	616	108
RTOR flow rate (veh/h)	0			0			0			0		
Percentage heavy vehicles	5%	4%	5%	4%	5%	9%	2%	4%	7%	0%	5%	8%
Platoon ratio	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Upstream filtering adjustment factor	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Initial queue (veh)	4	5	3	9	15	15	6	6	6	7	11	11
Base saturation flow	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Pedestrian flow rate (ped/h)	104			204			76			212		
Bicycle flow rate (bicycles/h)	0			0			0			0		
On-Street parking maneuver rate (veh/h)	0			0			0			0		
Local bus stopping rate (buses/h)	0			0			0			0		
Midsegment 85th percentile speed (mi/h)	30			30			30			30		
Number of right-turn islands	0			0			0			0		

Table D3: Traffic characteristics of the intersection W Univ. Ave. & 13th St.(Analysis period 2)

Traffic Characteristics	**EB**			**WB**			**NB**			**SB**		
	L	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	140	492	124	44	450	94	336	706	210	108	558	138
RTOR flow rate (veh/h)	0			0			0			0		
Percentage heavy vehicles	5%	2%	2%	0%	0%	0%	0%	2%	2%	0%	2%	1%
Pedestrian flow rate (ped/h)	116			88			68			164		
Bicycle flow rate (bicycles/h)	0			0			0			0		
On-Street parking maneuver rate (veh/h)	0			0			0			0		
Local bus stopping rate (buses/h)	0			0			0			0		

Table D4: Traffic characteristics of the intersection W Univ. Ave. & 13th St.(Analysis period 3)

Traffic Characteristics	**EB**			**WB**			**NB**			**SB**		
	L	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	153	490	200	82	434	86	228	682	186	111	635	130
RTOR flow rate (veh/h)	0			0			0			0		
Percentage heavy vehicles	0%	2%	5%	1%	2%	5%	1%	2%	4%	0%	3%	4%
Pedestrian flow rate (ped/h)	141			161			156			125		
Bicycle flow rate (bicycles/h)	0			0			0			0		
On-Street parking maneuver rate (veh/h)	0			0			0			0		
Local bus stopping rate (buses/h)	0			0			0			0		

Table D5: Signal timing data of the intersection W Univ. Ave. & 13th St.

Phase Information	**EBL**	**EBT**	**WBL**	**WBT**	**NBL**	**NBT**	**SBL**	**SBT**
Maximum Green (Gmax) or Phase Split, s	25	45	25	45	30	70	25	55
Yellow Change Interval (Y), s	3.7	3.7	3.7	3.7	3.8	3.8	3.8	3.8
Red Clearance Interval (Rc), s	2	2	2	2	2	2	2	2
Minimum Green (Gmin), s	7	12	7	12	7	12	7	12
Start-Up Lost Time (lt), s	2	2	2	2	2	2	2	2
Extension of Effective Green (e), s	2	2	2	2	2	2	2	2
Passage (PT), s	3	3.5	3	3.5	3	3.5	2.5	3.5
Recall Mode	Off	Off	Off	Off	Off	Off	Off	Off
Dual Entry	No	Yes	No	Yes	No	Yes	No	Yes
Walk (Walk), s		7		7		7		7
Pedestrian Clearance Time (PC), s		24		22		22		23

2. W Univ. Ave. & 17th St.

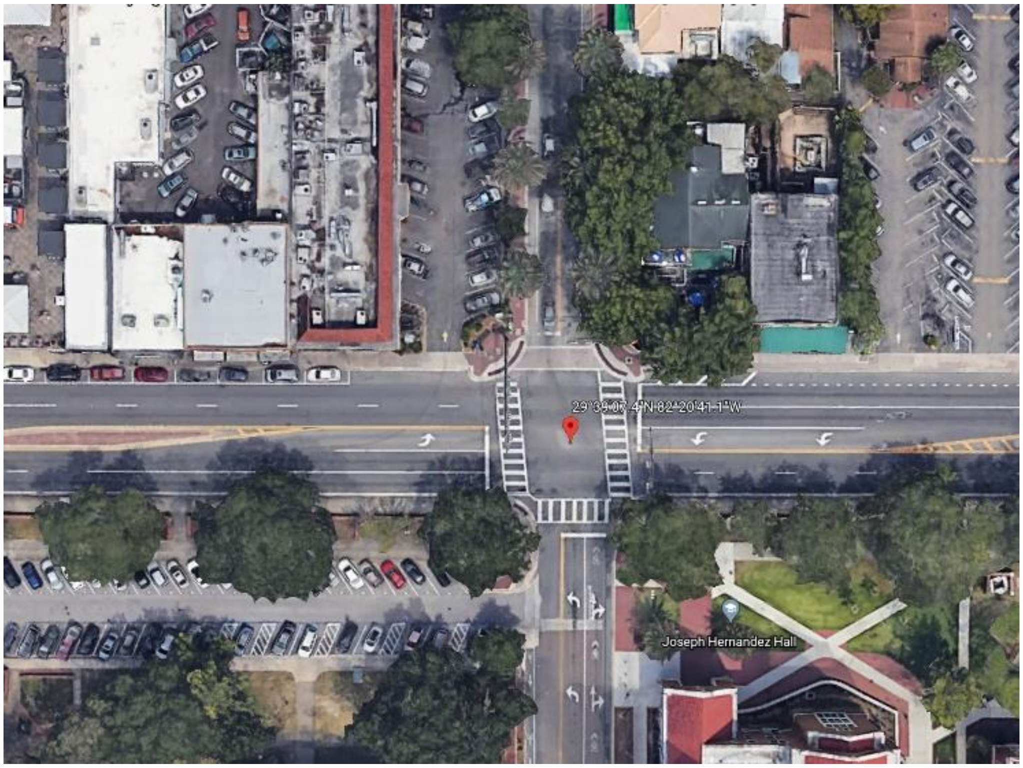


Figure D3: Layout and lane configuration of the intersection W Univ. Ave. & 17th St.

Table D6: Geometric data of the intersection W Univ. Ave. & 17th St.

Geometric Data	EB		WB		NB			SB		
	L	Th	L	Th	L	Th	R	L	Th	R
Number of lanes	3		3		2			1		
Average lane width (ft)	11		11		11			11		
Number of receiving lanes (ln)	2		2		1			1		
Turn bay length (ft)	130	410	130	860	130	320	320	185	185	185
Presence of on-street parking	Y		Y		N			N		
Approach grade (%)	0		0		0			0		
Total walkway width (ft)	10		10		10			10		
Crosswalk width (ft)	10		10		10			10		
Crosswalk length (ft)	64		64		52			52		
Corner radius (ft)	15		15		20			20		

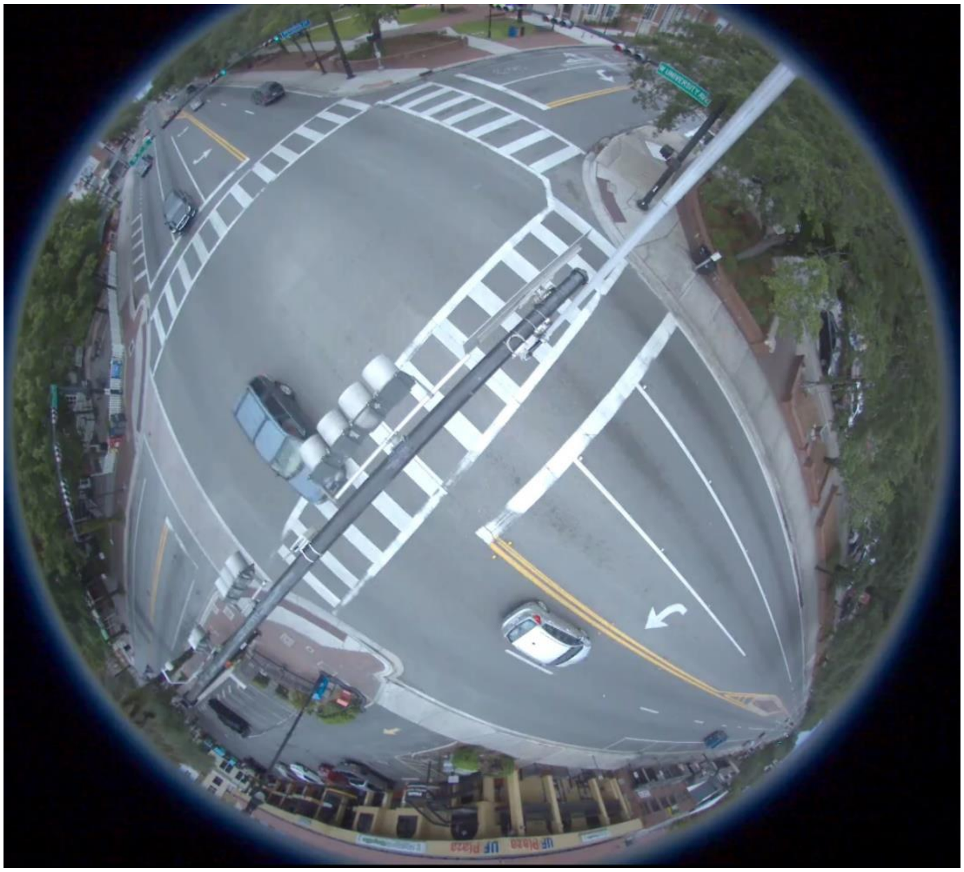


Figure D4: Fisheye camera view of the intersection W Univ. Ave. & 17th St.

Table D7: Traffic characteristics of the intersection W Univ. Ave. & 17th St.(Analysis period 1)

Traffic Characteristics	**EB**		**WB**		**NB**			**SB**		
	L	**Th**	**L**	**Th**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	20	520	8	692	8	20	8	16	20	36
RTOR flow rate (veh/h)	0		0		12			24		
Percentage heavy vehicles	0%	5%	0%	2%	0%	0%	0%	4%	0%	4%
Platoon ratio	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Upstream filtering adjustment factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Initial queue (veh)	0	2	0	3	0	1	0	1	0	0
Base saturation flow	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Pedestrian flow rate (ped/h)	12		4		8			12		
Bicycle flow rate (bicycles/h)	0		0		0			0		
On-Street parking maneuver rate (veh/h)	0		0		0			0		
Local bus stopping rate (buses/h)	0		0		0			0		
Midsegment 85th percentile speed (mi/h)	30		30		30			30		
Number of right-turn islands	0		0		0			0		

Table D8: Traffic characteristics of the intersection W Univ. Ave. & 17th St. (Analysis period 2)

Traffic Characteristics	**EB**		**WB**		**NB**			**SB**		
	L	**Th**	**L**	**Th**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	16	388	24	416	4	4	24	16	44	24
RTOR flow rate (veh/h)	0		0		16			24		
Percentage heavy vehicles	0%	4%	0%	4%	0%	0%	0%	0%	0%	0%
Pedestrian flow rate (ped/h)	0		4		4			12		
Bicycle flow rate (bicycles/h)	0		0		0			0		
On-Street parking maneuver rate (veh/h)	0		4		0			0		
Local bus stopping rate (buses/h)	0		0		0			0		

Table D9: Traffic characteristics of the intersection W Univ. Ave. & 17th St. (Analysis period 3)

Traffic Characteristics	**EB**		**WB**		**NB**			**SB**		
	L	**Th**	**L**	**Th**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	32	628	36	492	16	24	8	16	4	16
RTOR flow rate (veh/h)	0		0		8			12		
Percentage heavy vehicles	0%	1%	0%	3%	0%	0%	0%	0%	0%	0%
Pedestrian flow rate (ped/h)	0		4		16			0		
Bicycle flow rate (bicycles/h)	0		0		0			0		
On-Street parking maneuver rate (veh/h)	0		0		0			0		
Local bus stopping rate (buses/h)	0		0		0			0		

Table D10: Traffic characteristics of the intersection W Univ. Ave. & 17th St. (Analysis period 4)

Traffic Characteristics	**EB**		**WB**		**NB**			**SB**		
	L	**Th**	**L**	**Th**	**L**	**Th**	**R**	**L**	**Th**	**R**
Traffic flow rate (veh/h)	20	628	16	476	8	20	16	16	36	44
RTOR flow rate (veh/h)	0		0		16			36		
Percentage heavy vehicles	0%	3%	0%	2%	0%	0%	0%	0%	0%	0%
Pedestrian flow rate (ped/h)	0		8		4			0		
Bicycle flow rate (bicycles/h)	0		0		0			0		
On-Street parking maneuver rate (veh/h)	0		4		0			0		
Local bus stopping rate (buses/h)	0		0		0			0		

Table D11: Signal timing data of the intersection W Univ. Ave. & 17th St.

Phase Information	**EBL**	**EBT**	**WBL**	**WBT**	**NBL**	**NBT**	**SBL**	**SBT**
Maximum Green (Gmax) or Phase Split, s	25	55	25	55	25	55		40
Yellow Change Interval (Y), s	4	3.7	4	3.7	4	3.4		3.4
Red Clearance Interval (Rc), s	2	2	2	2	2.2	2.4		2.4
Minimum Green (Gmin), s	5	12	5	12	5	4		4
Start-Up Lost Time (lt), s	2	2	2	2	2	2	2	2
Extension of Effective Green (e), s	2	2	2	2	2	2	2	2
Passage (PT), s	2.5	3.5	2.5	3.5	2	3		2
Recall Mode	Off	Min	Off	Min	Off	Off		Off
Dual Entry	No	Yes	No	Yes	No	Yes		Yes
Walk (Walk), s		7		7		7		7
Pedestrian Clearance Time (PC), s		14		12		19		19

3. W Univ. Ave. & Gale Lemerand Dr.

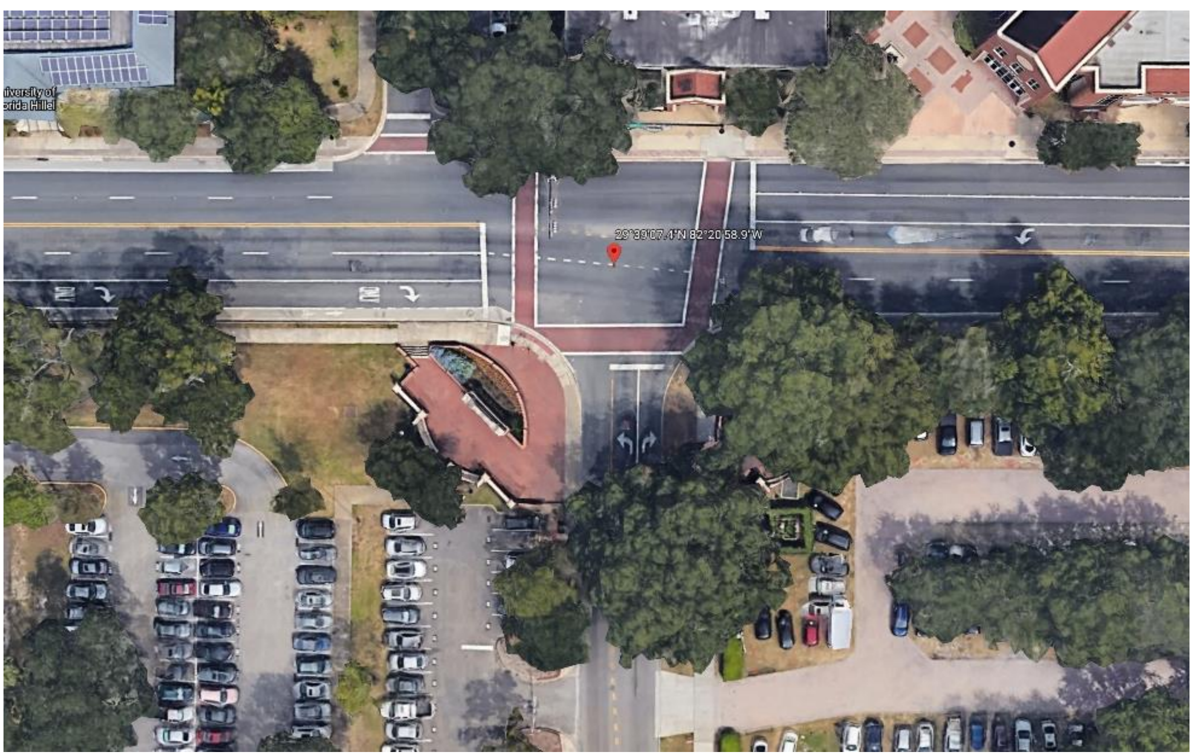


Figure D5: Layout and lane configuration of the intersection W Univ. Ave. & Gale Lemerand Dr.

Table D12: Geometric data of the intersection W Univ. Ave. & Gale Lemerand Dr.

Geometric Data	**EB**		**WB**		**NB**	
	Th	**R**	**L**	**Th**	**L**	**R**
Total walkway width (ft)	6		10		10	
Crosswalk width (ft)	11		N/A		10	
Crosswalk length (ft)	60		N/A		65	
Corner radius (ft)	30		N/A		30	
Number of lanes	3		3		2	
Average lane width (ft)	11		11		11	
Number of receiving lanes (ln)	2		2		-	
Turn bay length (ft)	290	300	340	520	110	100
Presence of on-street parking	0		0		0	
Approach grade (%)	0		0		0	

Figure D6: Fisheye camera view of the intersection W Univ. Ave. & Gale Lemerand Dr.

Table D13: Traffic characteristics of the intersection W Univ. Ave. & Gale Lemerand Dr. (Analysis period 1)

Traffic Characteristics	EB		WB		NB	
	Th	R	L	Th	L	R
Traffic flow rate (veh/h)	804	60	180	820	60	32
RTOR flow rate (veh/h)	0		N/A		100	
Percentage heavy vehicles	2%	0%	3%	1%	0%	6%
Platoon ratio	1.0	1.0	1.0	1.0	1.0	1.0
Upstream filtering adjustment factor	1.0	1.0	1.0	1.0	1.0	1.0
Initial queue (veh)	5	0	1	2	2	0
Base saturation flow	1900	1900	1900	1900	1900	1900
Pedestrian flow rate (ped/h)	0		4		88	
Bicycle flow rate (bicycles/h)	0		0		0	
On-Street parking maneuver rate (veh/h)	0		0		0	
Local bus stopping rate (buses/h)	0		0		0	
Midsegment 85th percentile speed (mi/h)	30		30		20	
Number of right-turn islands	0		0		0	

Table D14: Traffic characteristics of the intersection W Univ. Ave. & Gale Lemerand Dr. (Analysis period 2)

Traffic Characteristics	EB		WB		NB	
	Th	R	L	Th	R	L
Traffic flow rate (veh/h)	912	52	200	832	160	96
RTOR flow rate (veh/h)	20		N/A		96	
Percentage heavy vehicles	2%	0%	12%	2%	0%	4%
Pedestrian flow rate (ped/h)	4		40		20	
Bicycle flow rate (bicycles/h)	0		0		0	
On-Street parking maneuver rate (veh/h)	0		0		0	
Local bus stopping rate (buses/h)	0		0		0	

Table D15: Traffic characteristics of the intersection W Univ. Ave. & Gale Lemerand Dr. (Analysis period 3)

Traffic Characteristics	EB		WB		NB	
	Th	R	L	Th	L	R
Traffic flow rate (veh/h)	884	61	201	800	87	56
RTOR flow rate (veh/h)	45		N/A		112	
Percentage heavy vehicles	2%	0%	7%	2%	0%	5%
Pedestrian flow rate (ped/h)	11		22		81	
Bicycle flow rate (bicycles/h)	0		0		0	
On-Street parking maneuver rate (veh/h)	0		0		0	
Local bus stopping rate (buses/h)	0		0		0	

Table D16: Signal timing data of the intersection W Univ. Ave. & Gale Lemerand Dr.

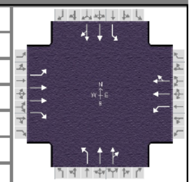
Phase Information	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Maximum Green (*Gmax*) or Phase Split, s		45	25	65		35		
Yellow Change Interval (*Y*), s		3.7	3.7	3.7		3.4		
Red Clearance Interval (*Rc*), s		2	2	2		3.2		
Minimum Green (*Gmin*), s		12	5	12		4		
Start-Up Lost Time (*lt*), s		2	2	2	2			
Extension of Effective Green (*e*), s		2	2	2	2			
Passage (*PT*), s		2	2	2		2		
Recall Mode		Min	Min	Off		Off		
Dual Entry		Yes	No	Yes		No		
Walk (*Walk*), s		7				7		
Pedestrian Clearance Time (*PC*), s		18				21		

HCS summary results for the signalized intersections

1. W Univ. Ave. & 13th St.

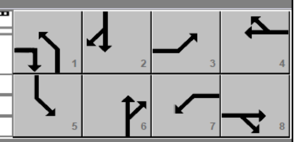
HCS7 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency	UFTI			Duration, h	0.25
Analyst	Muhammad Saif Uddin	Analysis Date	Mar 13, 2020	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	13th St	Analysis Year	2020	Analysis Period	1> 14:00
Intersection	W Univ Ave @ 13th St	File Name	W Uni Ave @ 13th St.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	160	356	220	92	340	80	264	612	200	76	616	108

Signal Information										
Cycle, s	136.8	Reference Phase	2							
Offset, s	0	Reference Point	End	Green	7.6	10.1	38.9	9.3	0.3	29.0
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	3.8	3.8	3.8	3.7	3.7	3.7
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	2.0	2.0	2.0	2.0	2.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	3	8	7	4	1	6	5	2
Case Number	2.0	3.0	2.0	4.0	2.0	4.0	2.0	4.0
Phase Duration, s	22.5	42.2	17.3	37.0	30.3	63.6	13.8	47.1
Change Period, (*Y+R* c), s	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.8
Max Allow Headway (*MAH*), s	4.2	4.8	4.2	4.8	4.2	4.7	3.7	4.7
Queue Clearance Time (*g* s), s	15.0	17.5	9.5	19.0	23.0	27.6	8.0	29.8
Green Extension Time (*g* e), s	0.3	5.8	0.2	5.8	0.5	10.3	0.1	9.1
Phase Call Probability	1.00	1.00	0.96	1.00	1.00	1.00	0.94	1.00
Max Out Probability	0.01	0.03	0.00	0.04	0.19	0.06	0.00	0.22

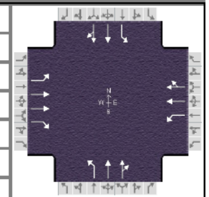
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	3	8	18	7	4	14	1	6	16	5	2	12
Adjusted Flow Rate (*v*), veh/h	160	356	220	92	227	193	264	430	382	76	387	337
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1565	1590	1232	1578	1683	1337	1603	1697	1502	1629	1670	1440
Queue Service Time (*g* s), s	13.0	12.0	15.5	7.5	15.7	17.0	21.0	25.5	25.6	6.0	27.4	27.8
Cycle Queue Clearance Time (*g* c), s	13.0	12.0	15.5	7.5	15.7	17.0	21.0	25.5	25.6	6.0	27.4	27.8
Green Ratio (*g/C*)	0.12	0.27	0.45	0.07	0.22	0.22	0.18	0.42	0.42	0.06	0.30	0.30
Capacity (*c*), veh/h	197	854	583	137	377	301	278	717	636	95	502	437
Volume-to-Capacity Ratio (*X*)	0.813	0.417	0.377	0.672	0.601	0.641	0.951	0.600	0.601	0.799	0.771	0.771
Back of Queue (*Q*), ft/ln (50 th percentile)	226	149.8	140.1	179.1	183	157.7	341.3	281.2	249.5	72.8	341.5	294.3
Back of Queue (*Q*), veh/ln (50 th percentile)	8.7	5.9	5.4	6.9	7.2	6.3	13.4	11.2	10.0	2.9	13.3	11.8
Queue Storage Ratio (*RQ*) (50 th percentile)	0.50	0.22	0.58	0.75	0.30	0.26	1.10	0.52	0.46	0.15	0.58	0.51
Uniform Delay (*d* 1), s/veh	63.0	41.0	25.0	63.1	45.9	46.4	66.2	29.6	29.6	63.7	43.6	43.4
Incremental Delay (*d* 2), s/veh	9.4	0.4	0.5	5.6	1.9	2.7	29.6	1.0	1.1	10.8	3.8	4.5
Initial Queue Delay (*d* 3), s/veh	24.8	1.1	0.3	57.3	0.3	0.5	1.9	0.1	0.2	0.0	1.5	2.0
Control Delay (*d*), s/veh	97.2	42.4	25.8	126.0	48.1	49.6	97.8	30.8	30.9	74.5	49.0	49.9
Level of Service (LOS)	F	D	C	F	D	D	F	C	C	E	D	D
Approach Delay, s/veh / LOS	49.4		D	62.6		E	47.3		D	51.8		D
Intersection Delay, s/veh / LOS	51.4						D					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.71	C	2.64	C	2.54	C	2.71	C
Bicycle LOS Score / LOS	1.09	A	0.91	A	1.38	A	1.15	A

Figure D7: Summary results of the signal W Univ. Ave. & 13th St. [Analysis Period 1]

HCS7 Signalized Intersection Results Summary

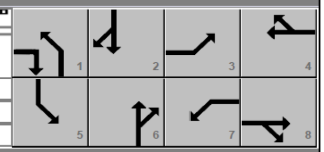
General Information				Intersection Information	
Agency	UFTI			Duration, h	0.25
Analyst	Muhammad Saif Uddin	Analysis Date	Mar 13, 2020	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	13th St	Analysis Year	2020	Analysis Period	2> 14:15
Intersection	W Univ Ave @ 13th St	File Name	W Uni Ave @ 13th St.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	140	492	124	44	452	96	336	708	212	108	560	140

Signal Information				
Cycle, s	141.4	Reference Phase	2	
Offset, s	0	Reference Point	End	
Uncoordinated	Yes	Simult. Gap E/W	On	
Force Mode	Fixed	Simult. Gap N/S	On	

Green	10.9	13.0	38.8	5.7	2.8	30.3
Yellow	3.8	3.8	3.8	3.7	3.7	3.7
Red	2.0	2.0	2.0	2.0	2.0	2.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	3	8	7	4	1	6	5	2
Case Number	2.0	3.0	2.0	4.0	2.0	4.0	2.0	4.0
Phase Duration, s	20.4	46.3	11.5	37.4	35.6	66.6	17.1	48.1
Change Period, ($Y+R_c$), s	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.8
Max Allow Headway (*MAH*), s	4.2	4.7	4.2	4.7	4.2	4.7	3.7	4.7
Queue Clearance Time (g_s), s	14.0	19.6	5.6	23.9	29.7	33.1	10.9	29.1
Green Extension Time (g_e), s	0.3	6.7	0.1	6.3	0.1	10.7	0.2	9.7
Phase Call Probability	0.99	1.00	0.81	1.00	1.00	1.00	0.98	1.00
Max Out Probability	0.00	0.07	0.00	0.13	1.00	0.11	0.00	0.24

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	3	8	18	7	4	14	1	6	16	5	2	12
Adjusted Flow Rate (*v*), veh/h	140	492	124	44	287	261	336	485	435	108	362	338
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1565	1603	1272	1629	1710	1520	1629	1710	1531	1629	1670	1554
Queue Service Time (g_s), s	12.0	17.6	7.3	3.6	21.4	21.9	27.7	31.1	31.1	8.9	26.9	27.1
Cycle Queue Clearance Time (g_c), s	12.0	17.6	7.3	3.6	21.4	21.9	27.7	31.1	31.1	8.9	26.9	27.1
Green Ratio (*g/C*)	0.10	0.29	0.50	0.04	0.22	0.22	0.22	0.42	0.42	0.08	0.29	0.29
Capacity (*c*), veh/h	163	920	680	66	383	340	310	725	649	130	497	462
Volume-to-Capacity Ratio (*X*)	0.860	0.535	0.182	0.662	0.751	0.767	1.084	0.670	0.670	0.831	0.728	0.732
Back of Queue (*Q*), ft/ln (50 th percentile)	143.7	187.4	55.2	44.3	248.2	228.8	468.1	328.7	295.2	105	302.2	277.6
Back of Queue (*Q*), veh/ln (50 th percentile)	5.5	7.4	2.2	1.8	9.9	9.2	18.7	13.1	11.8	4.2	11.8	11.1
Queue Storage Ratio (*RQ*) (50 th percentile)	0.32	0.27	0.23	0.18	0.41	0.38	1.51	0.60	0.54	0.22	0.51	0.48
Uniform Delay (d_1), s/veh	62.4	42.5	18.6	66.9	51.2	51.5	63.8	31.6	31.6	64.2	44.5	44.5
Incremental Delay (d_2), s/veh	12.2	0.6	0.2	10.7	3.7	4.8	72.7	1.7	1.9	9.7	3.0	3.3
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control Delay (*d*), s/veh	74.6	43.1	18.7	77.7	55.0	56.3	136.5	33.3	33.5	73.8	47.4	47.8
Level of Service (LOS)	E	D	B	E	D	E	F	C	C	E	D	D

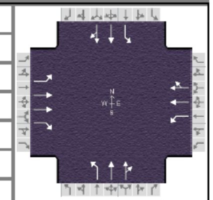
	EB		WB		NB		SB	
Approach Delay, s/veh / LOS	44.9	D	57.2	E	60.9	E	51.1	D
Intersection Delay, s/veh / LOS	54.4				D			

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.71	C	2.66	C	2.59	C	2.75	C
Bicycle LOS Score / LOS	1.11	A	0.98	A	1.52	B	1.15	A

Figure D8: Summary results of the signal W Univ. Ave. & 13th St. [Analysis Period 2]

HCS7 Signalized Intersection Results Summary

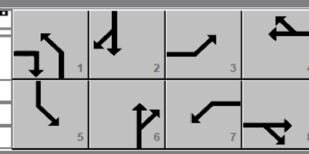
General Information				Intersection Information	
Agency	UFTI			Duration, h	0.25
Analyst	Muhammad Saif Uddin	Analysis Date	Mar 13, 2020	Area Type	CBD
Jurisdiction		Time Period		PHF	1.00
Urban Street	13th St	Analysis Year	2020	Analysis Period	3> 14:30
Intersection	W Univ Ave @ 13th St	File Name	W Uni Ave @ 13th St.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	152	488	200	84	436	88	228	684	188	112	636	132

Signal Information			
Cycle, s	129.6	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On

Green	10.5	3.5	39.7	8.2	5.6	29.0
Yellow	3.8	3.8	3.8	3.7	0.0	3.7
Red	2.0	2.0	2.0	2.0	0.0	2.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	3	8	7	4	1	6	5	2
Case Number	2.0	3.0	2.0	4.0	2.0	4.0	2.0	4.0
Phase Duration, s	19.9	41.1	14.1	35.3	28.0	57.7	16.6	46.4
Change Period, ($Y+R_c$), s	5.7	5.7	5.7	5.7	5.8	5.8	5.8	5.8
Max Allow Headway (*MAH*), s	4.2	4.8	4.2	4.8	4.2	4.7	3.7	4.7
Queue Clearance Time (g_s), s	13.5	18.3	8.4	21.8	19.2	30.9	10.5	29.7
Green Extension Time (g_e), s	0.3	7.3	0.2	7.0	0.6	11.3	0.2	9.9
Phase Call Probability	1.00	1.00	0.95	1.00	1.00	1.00	0.98	1.00
Max Out Probability	0.00	0.08	0.00	0.12	0.01	0.11	0.00	0.26

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	3	8	18	7	4	14	1	6	16	5	2	12
Adjusted Flow Rate (*v*), veh/h	152	488	200	84	279	245	228	468	404	112	405	363
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1629	1603	1179	1616	1697	1442	1629	1710	1476	1629	1670	1487
Queue Service Time (g_s), s	11.5	16.3	14.5	6.4	19.0	19.8	17.2	28.8	28.9	8.5	27.5	27.7
Cycle Queue Clearance Time (g_c), s	11.5	16.3	14.5	6.4	19.0	19.8	17.2	28.8	28.9	8.5	27.5	27.7
Green Ratio (*g/C*)	0.11	0.28	0.44	0.07	0.23	0.23	0.16	0.39	0.39	0.08	0.32	0.32
Capacity (*c*), veh/h	179	876	559	105	388	329	277	684	592	136	524	466
Volume-to-Capacity Ratio (*X*)	0.849	0.557	0.358	0.797	0.719	0.744	0.823	0.684	0.684	0.822	0.774	0.779
Back of Queue (*Q*), ft/ln (50 th percentile)	135.6	172.6	109.2	78.2	218.1	192.9	267.3	307.6	267.5	99	314.3	276.8
Back of Queue (*Q*), veh/ln (50 th percentile)	5.4	6.8	4.2	3.1	8.7	7.7	10.7	12.3	10.7	4.0	12.3	11.1
Queue Storage Ratio (*RQ*) (50 th percentile)	0.30	0.25	0.45	0.33	0.36	0.32	0.86	0.56	0.49	0.21	0.53	0.48
Uniform Delay (d_1), s/veh	56.7	40.5	24.2	59.8	46.2	46.6	52.9	32.1	32.1	58.5	40.4	40.5
Incremental Delay (d_2), s/veh	10.6	0.7	0.5	12.7	3.0	4.0	9.5	1.5	1.7	8.8	3.9	4.5
Initial Queue Delay (d_3), s/veh	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0
Control Delay (*d*), s/veh	67.3	41.1	24.6	72.5	49.3	50.6	84.6	33.5	33.8	67.4	44.3	45.0
Level of Service (LOS)	E	D	C	E	D	D	F	C	C	E	D	D
Approach Delay, s/veh / LOS	41.9	D		53.0	D		44.2	D		47.5	D	
Intersection Delay, s/veh / LOS	46.1						D					

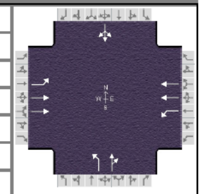
Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.71	C	2.67	C	2.59	C	2.73	C
Bicycle LOS Score / LOS	1.18	A	0.99	A	1.40	A	1.21	A

Figure D9: Summary results of the intersection W Univ. Ave. & 13th St. [Analysis Period 3]

2. W Univ. Ave. & 17th St.

HCS7 Signalized Intersection Results Summary

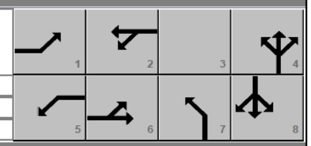
General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Apr 24, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Ave	Analysis Year	2020	Analysis Period	1> 14:00
Intersection	WUA @ 17th St	File Name	WUA@17thSt_mct.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (v), veh/h	20	520		8	692		8	20	8	16	20	36

Signal Information			
Cycle, s	50.0	Reference Phase	2
Offset, s	0	Reference Point	Begin
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On

Green	0.5	0.7	18.3	0.5	5.5	0.0
Yellow	4.0	0.0	3.7	4.0	3.4	0.0
Red	2.0	0.0	2.0	2.2	2.4	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	1	6	5	2	7	4		8
Case Number	1.1	4.0	1.1	4.0	1.0	4.0		8.3
Phase Duration, s	7.2	25.0	6.5	24.3	6.7	18.5		11.7
Change Period, ($Y+R_c$), s	6.0	5.7	6.0	5.7	6.2	5.8		5.8
Max Allow Headway (MAH), s	3.7	4.6	3.7	4.6	3.2	3.5		3.5
Queue Clearance Time (g_s), s	2.3	7.3	2.1	10.0	2.2	2.4		3.2
Green Extension Time (g_e), s	0.0	8.2	0.0	8.2	0.0	0.1		0.1
Phase Call Probability	0.24	1.00	0.10	1.00	0.10	0.65		0.61
Max Out Probability	0.00	0.00	0.00	0.01	0.00	0.00		0.00

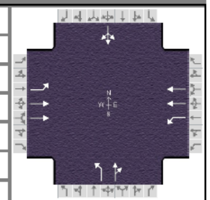
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	1	6		5	2		7	4	14	3	8	18
Adjusted Flow Rate (v), veh/h	20	520		8	692		8	0			48	
Adjusted Saturation Flow Rate (s), veh/h/ln	1810	1738		1810	1692		1810	0			1627	
Queue Service Time (g_s), s	0.3	5.3		0.1	8.0		0.2	0.0			0.0	
Cycle Queue Clearance Time (g_c), s	0.3	5.3		0.1	8.0		0.2	0.0			1.2	
Green Ratio (g/C)	0.40	0.38		0.38	0.37		0.16				0.11	
Capacity (c), veh/h	349	1340		376	1259		287				278	
Volume-to-Capacity Ratio (X)	0.057	0.388		0.021	0.550		0.028	0.000			0.173	
Back of Queue (Q), ft/ln (50 th percentile)	2.9	49.7		1.2	73.6		1.8	0			12.4	
Back of Queue (Q), veh/ln (50 th percentile)	0.1	1.9		0.0	2.9		0.1	0.0			0.5	
Queue Storage Ratio (RQ) (50 th percentile)	0.02	0.12		0.01	0.09		0.01	0.00			0.07	
Uniform Delay (d_1), s/veh	10.0	11.2		10.1	12.6		17.6				20.4	
Incremental Delay (d_2), s/veh	0.1	0.2		0.0	0.5		0.0	0.0			0.1	
Initial Queue Delay (d_3), s/veh	0.0	0.0		0.0	0.1		0.0	0.0			0.0	
Control Delay (d), s/veh	10.0	11.4		10.1	13.2		17.6				20.5	
Level of Service (LOS)	B	B		B	B		B				C	
Approach Delay, s/veh / LOS	11.4	B		13.2	B		15.2	B		20.5	C	
Intersection Delay, s/veh / LOS	12.7						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	1.94	B	1.78	B	2.53	C	2.53	C
Bicycle LOS Score / LOS	0.93	A	1.07	A	0.53	A	0.57	A

Figure D10: Summary results of the intersection W Univ. Ave. & 17th St. [Analysis Period 1]

HCS7 Signalized Intersection Results Summary

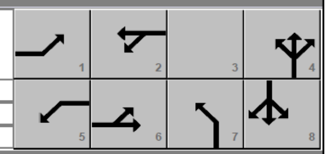
General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Apr 24, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Ave	Analysis Year	2020	Analysis Period	2> 14:15
Intersection	WUA @ 17th St	File Name	WUA@17thSt.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	16	388		24	416		4	4	24	16	44	24

Signal Information			
Cycle, s	41.8	Reference Phase	2
Offset, s	0	Reference Point	Begin
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On

Green	0.9	0.4	12.2	0.2	4.4	0.0
Yellow	4.0	0.0	3.7	4.0	3.4	0.0
Red	2.0	0.0	2.0	2.2	2.4	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	1	6	5	2	7	4		8
Case Number	1.1	4.0	1.1	4.0	1.0	4.0		8.3
Phase Duration, s	6.9	17.9	7.2	18.3	6.4	16.6		10.2
Change Period, ($Y+R_c$), s	6.0	5.7	6.0	5.7	6.2	5.8		5.8
Max Allow Headway (*MAH*), s	3.7	4.6	3.7	4.6	3.2	3.3		3.3
Queue Clearance Time (g_s), s	2.3	5.7	2.4	6.2	2.1	2.2		3.2
Green Extension Time (g_e), s	0.0	4.8	0.0	4.8	0.0	0.1		0.1
Phase Call Probability	0.17	1.00	0.24	1.00	0.05	0.59		0.57
Max Out Probability	0.00	0.00	0.00	0.00	0.00	0.00		0.00

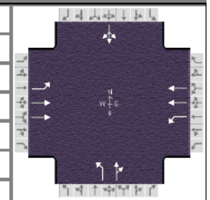
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	1	6		5	2		7	4	14	3	8	18
Adjusted Flow Rate (*v*), veh/h	16	388		24	416		4	12			60	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1810	1752		1810	1647		1810	1691			1785	
Queue Service Time (g_s), s	0.3	3.7		0.4	4.2		0.1	0.2			0.0	
Cycle Queue Clearance Time (g_c), s	0.3	3.7		0.4	4.2		0.1	0.2			1.2	
Green Ratio (*g/C*)	0.31	0.29		0.32	0.30		0.16	0.26			0.11	
Capacity (*c*), veh/h	359	1024		432	992		290	439			298	
Volume-to-Capacity Ratio (*X*)	0.045	0.379		0.056	0.419		0.014	0.027			0.201	
Back of Queue (*Q*), ft/ln (50 th percentile)	2.1	30.9		3.1	33.4		0.7	1.8			11.8	
Back of Queue (*Q*), veh/ln (50 th percentile)	0.1	1.2		0.1	1.3		0.0	0.1			0.5	
Queue Storage Ratio (*RQ*) (50 th percentile)	0.02	0.08		0.02	0.04		0.01	0.01			0.06	
Uniform Delay (d_1), s/veh	10.4	11.8		9.9	11.7		14.9	11.5			17.2	
Incremental Delay (d_2), s/veh	0.0	0.3		0.0	0.3		0.0	0.0			0.1	
Initial Queue Delay (d_3), s/veh	0.0	0.0		0.0	0.0		0.0	0.0			0.0	
Control Delay (*d*), s/veh	10.4	12.1		10.0	12.0		14.9	11.6			17.4	
Level of Service (LOS)	B	B		A	B		B	B			B	
Approach Delay, s/veh / LOS	12.0	B		11.9	B		12.4	B		17.4	B	
Intersection Delay, s/veh / LOS	12.3						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	1.95	B	1.76	B	2.45	B	2.43	B
Bicycle LOS Score / LOS	0.82	A	0.85	A	0.51	A	0.59	A

Figure D11: Summary results of the intersection W Univ. Ave. & 17th St. [Analysis Period 2]

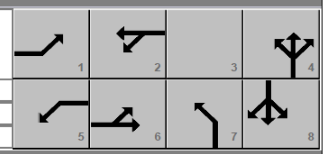
HCS7 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Apr 24, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Ave	Analysis Year	2020	Analysis Period	3> 14:30
Intersection	WUA @ 17th St	File Name	WUA@17thSt.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	32	628		36	492		16	24	8	16	4	16

Signal Information									
Cycle, s	46.9	Reference Phase	2						
Offset, s	0	Reference Point	Begin	Green	1.7	0.2	16.0	0.9	4.3	0.0
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	4.0	0.0	3.7	4.0	3.4	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	0.0	2.0	2.2	2.4	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	1	6	5	2	7	4		8
Case Number	1.1	4.0	1.1	4.0	1.0	4.0		8.3
Phase Duration, s	7.7	21.7	7.9	21.9	7.1	17.3		10.1
Change Period, (*Y+R c*), s	6.0	5.7	6.0	5.7	6.2	5.8		5.8
Max Allow Headway (*MAH*), s	3.7	4.6	3.7	4.6	3.2	3.7		3.7
Queue Clearance Time (*g s*), s	2.5	8.5	2.6	7.3	2.4	2.5		2.6
Green Extension Time (*g e*), s	0.0	7.3	0.1	7.3	0.0	0.1		0.1
Phase Call Probability	0.34	1.00	0.37	1.00	0.19	0.57		0.47
Max Out Probability	0.00	0.00	0.00	0.00	0.00	0.00		0.00

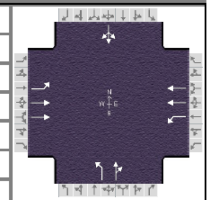
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	1	6		5	2		7	4	14	3	8	18
Adjusted Flow Rate (*v*), veh/h	32	628		36	492		16	0			24	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1810	1795		1810	1678		1810	0			1533	
Queue Service Time (*g s*), s	0.5	6.5		0.6	5.3		0.4	0.0			0.0	
Cycle Queue Clearance Time (*g c*), s	0.5	6.5		0.6	5.3		0.4	0.0			0.6	
Green Ratio (*g/C*)	0.38	0.34		0.38	0.35		0.16				0.09	
Capacity (*c*), veh/h	396	1229		391	1161		306				269	
Volume-to-Capacity Ratio (*X*)	0.081	0.511		0.092	0.424		0.052	0.000			0.089	
Back of Queue (*Q*), ft/ln (50 th percentile)	4.4	56.2		4.9	42.7		3.3	0			5.5	
Back of Queue (*Q*), veh/ln (50 th percentile)	0.2	2.2		0.2	1.7		0.1	0.0			0.2	
Queue Storage Ratio (*RQ*) (50 th percentile)	0.03	0.14		0.04	0.05		0.03	0.00			0.03	
Uniform Delay (*d 1*), s/veh	9.8	12.3		9.6	11.8		17.0				19.6	
Incremental Delay (*d 2*), s/veh	0.1	0.4		0.1	0.3		0.0	0.0			0.1	
Initial Queue Delay (*d 3*), s/veh	0.0	0.0		0.0	0.0		0.0	0.0			0.0	
Control Delay (*d*), s/veh	9.8	12.7		9.7	12.1		17.0				19.6	
Level of Service (LOS)	A	B		A	B		B				B	
Approach Delay, s/veh / LOS	12.6	B		11.9	B		15.0	B		19.6	B	
Intersection Delay, s/veh / LOS	12.5						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	1.98	B	1.77	B	2.52	C	2.52	C
Bicycle LOS Score / LOS	1.03	A	0.92	A	0.55	A	0.53	A

Figure D12: Summary results of the intersection W Univ. Ave. & 17th St. [Analysis Period 3]

HCS7 Signalized Intersection Results Summary

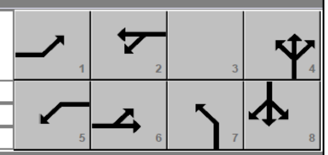
General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Apr 24, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Ave	Analysis Year	2020	Analysis Period	4> 14:45
Intersection	WUA @ 17th St	File Name	WUA@17thSt.xus		
Project Description					



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h	20	628		16	476		8	20	16	16	36	44

Signal Information			
Cycle, s	43.3	Reference Phase	2
Offset, s	0	Reference Point	Begin
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On

Green	0.9	0.2	15.2	0.5	2.9	0.0
Yellow	4.0	0.0	3.7	4.0	3.4	0.0
Red	2.0	0.0	2.0	2.2	2.4	0.0



Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase	1	6	5	2	7	4		8
Case Number	1.1	4.0	1.1	4.0	1.0	4.0		8.3
Phase Duration, s	7.1	21.1	6.9	20.9	6.7	15.4		8.7
Change Period, ($Y+R_c$), s	6.0	5.7	6.0	5.7	6.2	5.8		5.8
Max Allow Headway (*MAH*), s	3.7	4.6	3.7	4.6	3.2	3.4		3.4
Queue Clearance Time (g_s), s	2.3	7.9	2.2	6.6	2.2	2.4		3.3
Green Extension Time (g_e), s	0.0	7.2	0.0	7.2	0.0	0.1		0.1
Phase Call Probability	0.21	1.00	0.18	1.00	0.09	0.62		0.58
Max Out Probability	0.00	0.00	0.00	0.00	0.00	0.00		0.00

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement	1	6		5	2		7	4	14	3	8	18
Adjusted Flow Rate (*v*), veh/h	20	628		16	476		8	0			52	
Adjusted Saturation Flow Rate (*s*), veh/h/ln	1810	1809		1810	1700		1810	0			1717	
Queue Service Time (g_s), s	0.3	5.9		0.2	4.6		0.2	0.0			1.1	
Cycle Queue Clearance Time (g_c), s	0.3	5.9		0.2	4.6		0.2	0.0			1.3	
Green Ratio (*g/C*)	0.38	0.35		0.37	0.35		0.12				0.07	
Capacity (*c*), veh/h	441	1285		344	1192		240				224	
Volume-to-Capacity Ratio (*X*)	0.045	0.489		0.046	0.399		0.033	0.000			0.232	
Back of Queue (*Q*), ft/ln (50 th percentile)	2.4	47.8		2	35.1		1.6	0			11.5	
Back of Queue (*Q*), veh/ln (50 th percentile)	0.1	1.9		0.1	1.4		0.1	0.0			0.5	
Queue Storage Ratio (*RQ*) (50 th percentile)	0.02	0.12		0.02	0.04		0.01	0.00			0.06	
Uniform Delay (d_1), s/veh	8.8	10.9		9.3	10.6		16.8				19.4	
Incremental Delay (d_2), s/veh	0.0	0.3		0.0	0.3		0.0	0.0			0.2	
Initial Queue Delay (d_3), s/veh	0.0	0.0		0.0	0.0		0.0	0.0			0.0	
Control Delay (*d*), s/veh	8.8	11.3		9.4	10.9		16.8				19.6	
Level of Service (LOS)	A	B		A	B		B				B	
Approach Delay, s/veh / LOS	11.2	B		10.8	B		14.3	B		19.6	B	
Intersection Delay, s/veh / LOS	11.5						B					

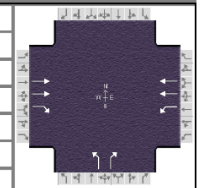
Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	1.96	B	1.81	B	2.50	C	2.50	B
Bicycle LOS Score / LOS	1.02	A	0.89	A	0.53	A	0.57	A

Figure D13: Summary results of the intersection W Univ. Ave. & 17th St. [Analysis Period 4]

3. W Univ. Ave. & Gale Lemerand Dr.

HCS7 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Mar 13, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Avenue	Analysis Year	2020	Analysis Period	1> 14:00
Intersection	Gale Lamerand	File Name	W Uni Ave @ GL.xus		
Project Description	13th of March				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (v), veh/h		804	60	180	820		60		32			

Signal Information									
Cycle, s	44.3	Reference Phase	2						
Offset, s	0	Reference Point	End	Green	6.4	15.2	2.7	0.0	0.0	0.0
Uncoordinated	Yes	Simult. Gap E/W	On	Yellow	3.7	3.7	3.4	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Red	2.0	2.0	3.2	0.0	0.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		2	1	6		8		
Case Number		7.3	2.0	4.0		9.0		
Phase Duration, s		21.6	12.5	34.1		10.1		
Change Period, ($Y+R_c$), s		5.7	5.7	5.7		6.6		
Max Allow Headway (*MAH*), s		3.1	3.2	3.1		3.8		
Queue Clearance Time (g_s), s		10.0	6.0	6.5		3.9		
Green Extension Time (g_e), s		4.9	0.3	4.9		0.2		
Phase Call Probability		1.00	1.00	1.00		0.66		
Max Out Probability		0.00	0.00	0.00		0.00		

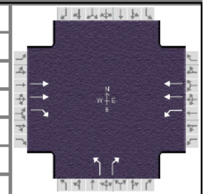
Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement		2	12	1	6		3		18			
Adjusted Flow Rate (v), veh/h		804	60	180	820		60		32			
Adjusted Saturation Flow Rate (s), veh/h/ln		1766	1598	1781	1781		1327		1514			
Queue Service Time (g_s), s		8.0	1.1	4.0	4.5		1.9		0.9			
Cycle Queue Clearance Time (g_c), s		8.0	1.1	4.0	4.5		1.9		0.9			
Green Ratio (g/C)		0.36	0.36	0.15	0.64		0.06		0.06			
Capacity (c), veh/h		1270	574	270	2294		97		106			
Volume-to-Capacity Ratio (X)		0.633	0.105	0.666	0.357		0.618		0.301			
Back of Queue (Q), ft/ln (50 th percentile)		81.8	8	44	24.4		36.4		7.6			
Back of Queue (Q), veh/ln (50 th percentile)		3.2	0.3	1.7	1.0		1.5		0.3			
Queue Storage Ratio (RQ) (50 th percentile)		0.28	0.03	0.13	0.05		0.33		0.08			
Uniform Delay (d_1), s/veh		12.4	9.4	17.7	3.6		20.1		19.2			
Incremental Delay (d_2), s/veh		0.2	0.0	1.1	0.0		2.4		0.6			
Initial Queue Delay (d_3), s/veh		0.3	0.0	0.3	0.0		18.0		0.0			
Control Delay (d), s/veh		12.9	9.5	19.0	3.7		40.4		19.8			
Level of Service (LOS)		B	A	B	A		D		B			
Approach Delay, s/veh / LOS	12.6	B		6.5	A		33.3	C		0.0		
Intersection Delay, s/veh / LOS	10.5						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.00	B	0.64	A	2.26	B	2.61	C
Bicycle LOS Score / LOS	1.20	A	1.31	A		F		

Figure D14: Summary results of the intersection W Univ. Ave. & Gale Lemerand Dr. [Analysis Period 1]

HCS7 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Mar 13, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Avenue	Analysis Year	2020	Analysis Period	2> 14:15
Intersection	Gale Lamerand	File Name	W Uni Ave @ GL.xus		
Project Description	13th of March				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h		912	52	200	832		96		160			

Signal Information			
Cycle, s	60.9	Reference Phase	2
Offset, s	0	Reference Point	End
Uncoordinated	Yes	Simult. Gap E/W	On
Force Mode	Fixed	Simult. Gap N/S	On

Green	9.5	22.0	11.4	0.0	0.0	0.0
Yellow	3.7	3.7	3.4	0.0	0.0	0.0
Red	2.0	2.0	3.2	0.0	0.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		2	1	6		8		
Case Number		7.3	2.0	4.0		9.0		
Phase Duration, s		27.7	15.2	42.9		18.0		
Change Period, ($Y+R_c$), s		5.7	5.7	5.7		6.6		
Max Allow Headway (*MAH*), s		3.1	3.2	3.1		3.4		
Queue Clearance Time (g_s), s		15.4	9.2	9.3		7.8		
Green Extension Time (g_e), s		5.3	0.3	5.5		0.6		
Phase Call Probability		1.00	1.00	1.00		0.99		
Max Out Probability		0.01	0.00	0.00		0.00		

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement		2	12	1	6		3		18			
Adjusted Flow Rate (*v*), veh/h		912	52	200	832		96		160			
Adjusted Saturation Flow Rate (*s*), veh/h/ln		1781	1601	1640	1766		1753		1533			
Queue Service Time (g_s), s		13.4	1.3	7.2	7.3		2.9		5.8			
Cycle Queue Clearance Time (g_c), s		13.4	1.3	7.2	7.3		2.9		5.8			
Green Ratio (*g/C*)		0.36	0.36	0.16	0.61		0.19		0.19			
Capacity (*c*), veh/h		1288	579	256	2159		328		287			
Volume-to-Capacity Ratio (*X*)		0.708	0.090	0.781	0.385		0.292		0.557			
Back of Queue (*Q*), ft/ln (50 th percentile)		124.8	10.8	75.1	52.1		28.9		49.7			
Back of Queue (*Q*), veh/ln (50 th percentile)		4.9	0.4	2.7	2.0		1.1		2.0			
Queue Storage Ratio (*RQ*) (50 th percentile)		0.43	0.04	0.22	0.10		0.26		0.50			
Uniform Delay (d_1), s/veh		16.7	12.9	24.7	6.0		21.3		22.5			
Incremental Delay (d_2), s/veh		0.3	0.0	2.0	0.0		0.2		0.6			
Initial Queue Delay (d_3), s/veh		0.0	0.0	0.0	0.0		0.0		0.0			
Control Delay (*d*), s/veh		17.0	12.9	26.7	6.1		21.5		23.1			
Level of Service (LOS)		B	B	C	A		C		C			

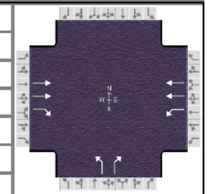
	EB		WB		NB		SB	
Approach Delay, s/veh / LOS	16.8	B	10.1	B	22.5	C	0.0	
Intersection Delay, s/veh / LOS	14.4				B			

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.08	B	0.66	A	2.28	B	2.66	C
Bicycle LOS Score / LOS	1.28	A	1.34	A		F		

Figure D15: Summary results of the intersection W Univ. Ave. & Gale Lemerand Dr. [Analysis Period 2]

HCS7 Signalized Intersection Results Summary

General Information				Intersection Information	
Agency				Duration, h	0.25
Analyst		Analysis Date	Mar 13, 2020	Area Type	Other
Jurisdiction		Time Period		PHF	1.00
Urban Street	West University Avenue	Analysis Year	2020	Analysis Period	3> 14:30
Intersection	Gale Lamerand	File Name	W Uni Ave @ GL.xus		
Project Description	13th of March				



Demand Information	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Demand (*v*), veh/h		884	60	200	800		88		56			

Signal Information										
Cycle, s	67.1	Reference Phase	2							
Offset, s	0	Reference Point	End							
Uncoordinated	Yes	Simult. Gap E/W	On	Green	10.0	22.6	16.5	0.0	0.0	0.0
Force Mode	Fixed	Simult. Gap N/S	On	Yellow	3.7	3.7	3.4	0.0	0.0	0.0
				Red	2.0	2.0	3.2	0.0	0.0	0.0

Timer Results	EBL	EBT	WBL	WBT	NBL	NBT	SBL	SBT
Assigned Phase		2	1	6		8		
Case Number		7.3	2.0	4.0		9.0		
Phase Duration, s		28.3	15.7	44.0		23.1		
Change Period, (*Y+R* c), s		5.7	5.7	5.7		6.6		
Max Allow Headway (*MAH*), s		3.1	3.2	3.1		3.4		
Queue Clearance Time (g_s), s		16.7	9.6	10.4		4.7		
Green Extension Time (g_e), s		5.1	0.3	5.2		0.3		
Phase Call Probability		1.00	1.00	1.00		0.93		
Max Out Probability		0.01	0.00	0.00		0.00		

Movement Group Results	EB			WB			NB			SB		
Approach Movement	L	T	R	L	T	R	L	T	R	L	T	R
Assigned Movement		2	12	1	6		3		18			
Adjusted Flow Rate (*v*), veh/h		884	60	200	800		88		56			
Adjusted Saturation Flow Rate (*s*), veh/h/ln		1781	1553	1697	1781		1739		1446			
Queue Service Time (g_s), s		14.7	1.8	7.6	8.4		2.7		2.0			
Cycle Queue Clearance Time (g_c), s		14.7	1.8	7.6	8.4		2.7		2.0			
Green Ratio (*g/C*)		0.34	0.34	0.15	0.57		0.25		0.25			
Capacity (*c*), veh/h		1201	523	253	2033		428		356			
Volume-to-Capacity Ratio (*X*)		0.736	0.115	0.791	0.393		0.206		0.157			
Back of Queue (*Q*), ft/ln (50 th percentile)		143	14.9	82.3	67.5		27.2		16.4			
Back of Queue (*Q*), veh/ln (50 th percentile)		5.6	0.6	3.1	2.7		1.0		0.7			
Queue Storage Ratio (*RQ*) (50 th percentile)		0.49	0.05	0.24	0.13		0.25		0.16			
Uniform Delay (d_1), s/veh		19.6	15.4	27.6	8.0		20.1		19.9			
Incremental Delay (d_2), s/veh		0.3	0.0	2.1	0.0		0.1		0.1			
Initial Queue Delay (d_3), s/veh		0.0	0.0	0.0	0.0		0.0		0.0			
Control Delay (*d*), s/veh		20.0	15.4	29.7	8.0		20.2		19.9			
Level of Service (LOS)		B	B	C	A		C		B			
Approach Delay, s/veh / LOS	19.7		B	12.4		B	20.1		C	0.0		
Intersection Delay, s/veh / LOS	16.2						B					

Multimodal Results	EB		WB		NB		SB	
Pedestrian LOS Score / LOS	2.06	B	0.67	A	2.28	B	2.65	C
Bicycle LOS Score / LOS	1.27	A	1.31	A		F		

Figure D16: Summary results of the intersection W Univ. Ave. & Gale Lemerand Dr. [Analysis Period 3]