CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

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Development of a Safety Advisory System to Aid Senior Citizens in Gap Selection

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The University of Akron

CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

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CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

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16. Abstract

Older drivers tend to suffer more from aging related issues concerning hearing and vision, the reaction time, and cognitive functions. This research aims to help older drivers select proper gaps by using connected vehicles technologies and an in-vehicle advisory system. A study was conducted on 79 old drivers (60 or older), among them 75.9% were male and 24.1% were females. The study was conducted at two unsignalized intersections in the Stow and Tallmadge in Ohio, and it included both a simulation and a field test. The field data showed that a safe gap of 7.4 seconds at the Stow location can be used without causing speed impedance to the oncoming vehicles, compared with 6.5 seconds recommended by HCM.

The in-vehicle safety advisory system provides warning through red flashing, beeping, and text messages on an LCD, if the upcoming gap is determined unsafe to use. When the system does not issue any warning message, it is the driver's responsibility to decide if or not to take the available gap. The test involves two scenarios, one is when all vehicles are connected and the other is in a mixed traffic situation with both ordinary vehicles and connected vehicles. Different hardware designs and field test procedures were used to separate the two cases.

The simulation runs used the field data to define modeling parameters. The measures of effectiveness (MOEs), such as average delay, queue length, and average waiting time, were obtained to assess the impact of running the advisory system. The field test results showed that 96% of the participants accept the system and agree that it can improve safety. Most of the participants claimed that they prefer a combination of beeping and red flashing rather than a single type of warning.

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Older Drivers, Gap Selection, Traffic Safety, Advisory System, Field Test	No restrictions.

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I. INTRODUCTION

A. Older Drivers

Older drivers (65 years and older) represent the fastest-growing driver segment in the driving population as well as the general population. It has been projected by U.S. Census Bureau that the elderly population will be around 80 million by 2050. Moreover, with the ageing of the general population, evidence suggests that there will be a substantial increase in licensing rates among older drivers (Dellinger et al., 2001).

Insurance Institute for Highway Safety (IIHS., 2019) reported that older people in the United States represent 11 percent, and this number increased yearly, as shown in Figure I.1.

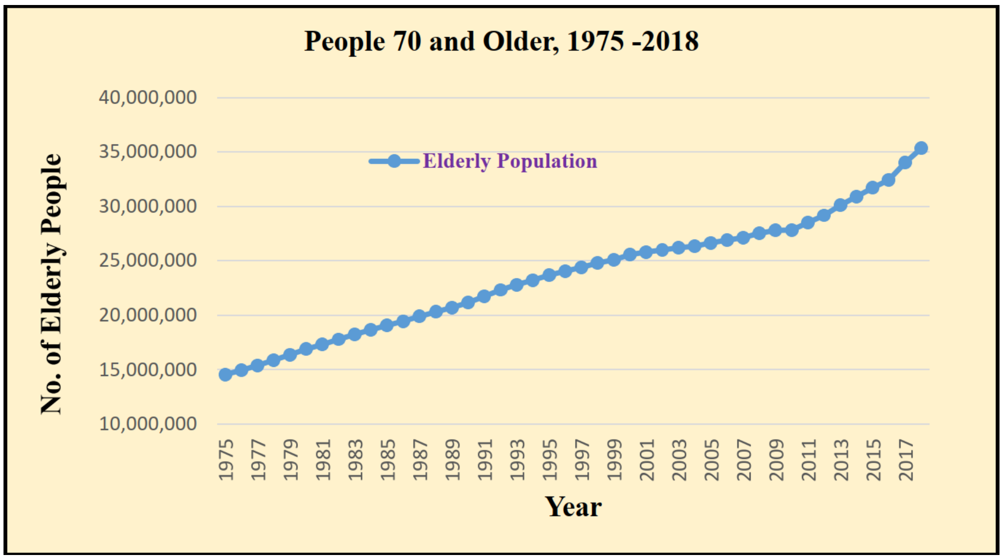

Figure I.1 - Increasing Elderly People from 1975 to 2018 (IIHS,2019)

Older drivers suffer from problems related to attention, cognition, and perception that influences their ability to accurately detect, perceive, and judge the safety of the gaps in a traffic flow before entering the roadway. Issues such as attending to singular source of information, divided attention, and limited useful field of view (UFOV) causes older drivers to make notable errors in analyzing approaching vehicles (Laberge et al., 2006, Hu et al., 1998). As a result, older adults are involved in 39% of intersection crashes as compared to a much lower rate by younger drivers. Insurance Institute for Highway Safety (IIHS., 2019) reported that in 2018 a total of 4,973 people ages 70 and older died in vehicle accidents, as shown in Figure I.2. It also reported a rising percentage of intersection fatal crashes in the same year after people reach 60, as shown in Figure I.3.

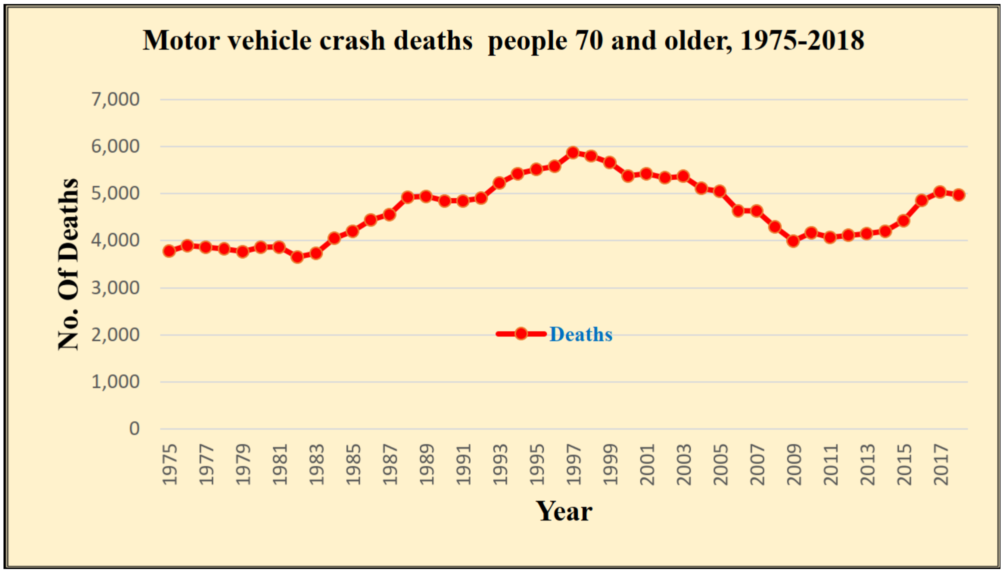

Figure I.2 - Deaths Crash People 70 and Older from 1975 to 2018 (IIHS,2019)

In 2030, the number of older drivers involved in fatal accidents – are expected to increase up to 178% (Bayam, Liebowitz and Agresti, 2005).

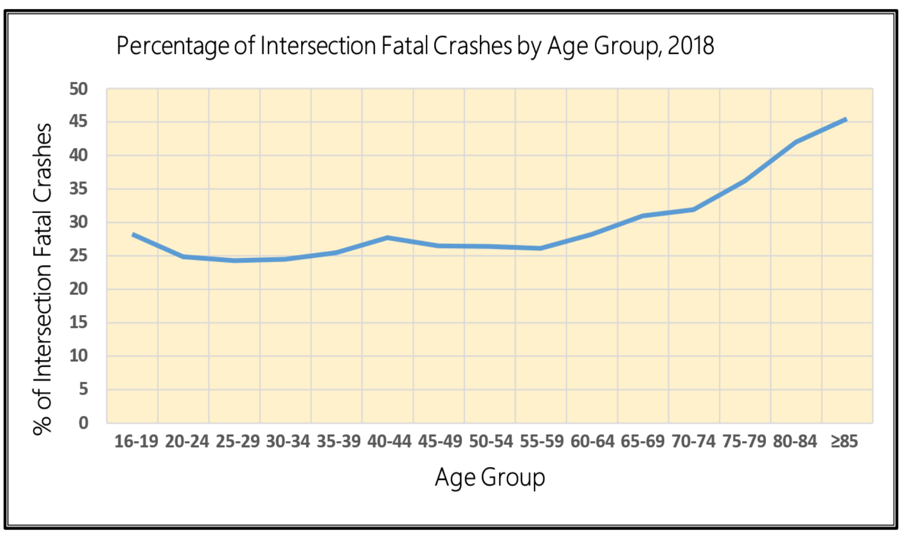

Figure I.3 - Increase Old Drivers Fatal Crashes at intersection in 2018 (IIHS, 2019)

B. Older Drivers at intersections

1. Older Drivers at Unsignalized Intersections

At an unsignalized intersection, two road traffic streams have different right-of-way priorities. The high priority stream does not need to observe the low priority stream when arriving at the intersection. However, the low priority stream vehicles can only cross the intersection when the gap duration is sufficiently larger between two subsequent vehicles (Abhishek et al., 2016). When negotiating at unsignalized intersection, the age of the drivers becomes crucial.

It is reported that older drivers stopped more frequently, had slower approach speeds and had difficulty in making effective left turns, especially at unsignalized intersections (Wu and Xu, 2017), as shown in Figure I.4.

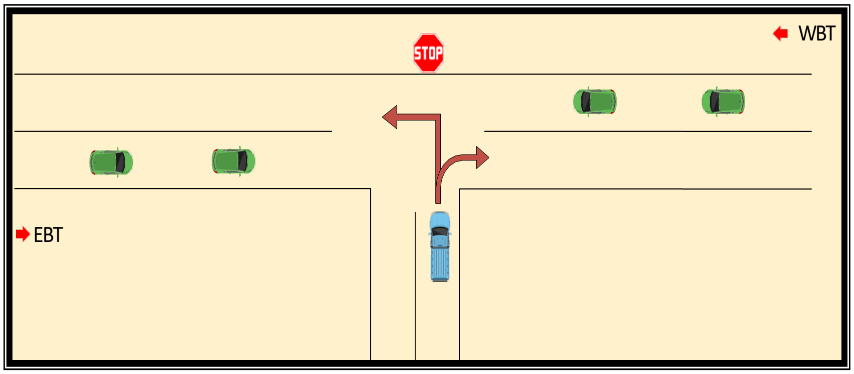

Figure I.4 - T intersection Controlled by Stop Sign

2. Gaps Selection for Older Drivers

Gap acceptance is the driver's willingness to accept a gap before entering an intersection. At two-way unsignalized intersection, traffic of lower priority stream must observe the traffic of higher priority stream before crossing the intersection. Most vehicle crashes at unsignalized intersections are caused by drivers selecting poor gaps when attempting to enter the intersection. This is especially true in the case of older drivers as they are relatively slow to respond to the speed of the approaching vehicle (Zhou et al., 2017). Older drivers experience a declining perceptual, sensory, and memory capacity that impacts their ability to select appropriate gaps; they are more likely to reject usable gaps and cause speed reductions to the oncoming mainline traffic (Yi, 2011).

Dutta and Ahmed (2018) mentioned that older driver's gap acceptance behavior driver is influenced by several factors which prominently include clearing time, gap duration, intersection characteristics, vehicle characteristics, type of control, pavement and light conditions, weather, and driver's psychological status.

C. Advanced Technology for Older Drivers

Traffic control systems have been continuously innovated and updated to keep up with the increasing demands of the traffic. Among various technologies that are designed to control road traffic network efficiently, connected and automated vehicles (CAVs) are believed to have the greatest potential. Guo, Li and Ban (2019) defined CAVs as automated vehicles that can utilize communications with traffic participants (V2X), the infrastructure (V2I), and other vehicles (V2V). With continuous advancements in computational power and perception technologies, the connected and self-driving functions are expected to gradually appear in the near future.

In a general driving setting, connected vehicle technology produces and captures traffic data in real-time to enhance the safety of road operations. It can also notify older drivers as soon as the system identifies a potential violation of signal-controlled intersection (Becic et al., 2018).

Due to the complex nature of unsignalized intersections, older drivers are demanded of high-level cognitive, visual, and motor skill abilities. Advanced lane-keeping assistance, adoptive cruise control (ACC), and Autopilot technologies can assist older drivers negotiate and maneuver at unsignalized intersections and maintain their mobility and independence (Classen et al., 2020).

In addition, advanced communication and vehicle control technologies can help identify optimal gap patterns, the critical gap, lane-changing and merging threshold, and the velocity of other vehicles. These parameters may be used to compensate for the age-related constraints of older drivers (Millonig, 2019).

D. Problem Statement

Older people constitute less than one-twelfth of the rural population, however, they are involved in one-sixth of the fatal crashes and accidents. In particular, older drivers have a higher accident rate at unsignalized intersections and a higher fatality rate in general, compared to the other driver age groups. One of the primary reasons for the problem at unsignalized intersections is selecting poor gaps by older drivers because of ageing-related issues. Thus, this research project intends to design and test a safety enhancement system, by using advanced vehicle location identification and data communication technologies, for older drivers in gap selection at unsignalized intersections. Specifically, this research will develop and evaluate the gap warning system at two unsignalized T intersections in Summit County, Ohio. Field data will be used to define the system parameters in the proposed safety advisory system.

E. Objectives of Study

This research project aims to achieve the following objectives:

1. Design and test an in-vehicle advisory system to help older drivers avoid selecting poor gaps to reduce the risk of accidents.
2. Conduct field tests at unsignalized intersections in different conditions to investigate gap selections of older drivers with the assistance of the advisory system.
3. Decide on the gap size selected that will not cause significant delays in the major road traffic flow.
4. Find out the preferred warning message presentation method by older drivers, including sound, light, and messaging through LCD.

The flow chart shown in Figure I.5 illustrates the methodological process to achieve the above research objectives:

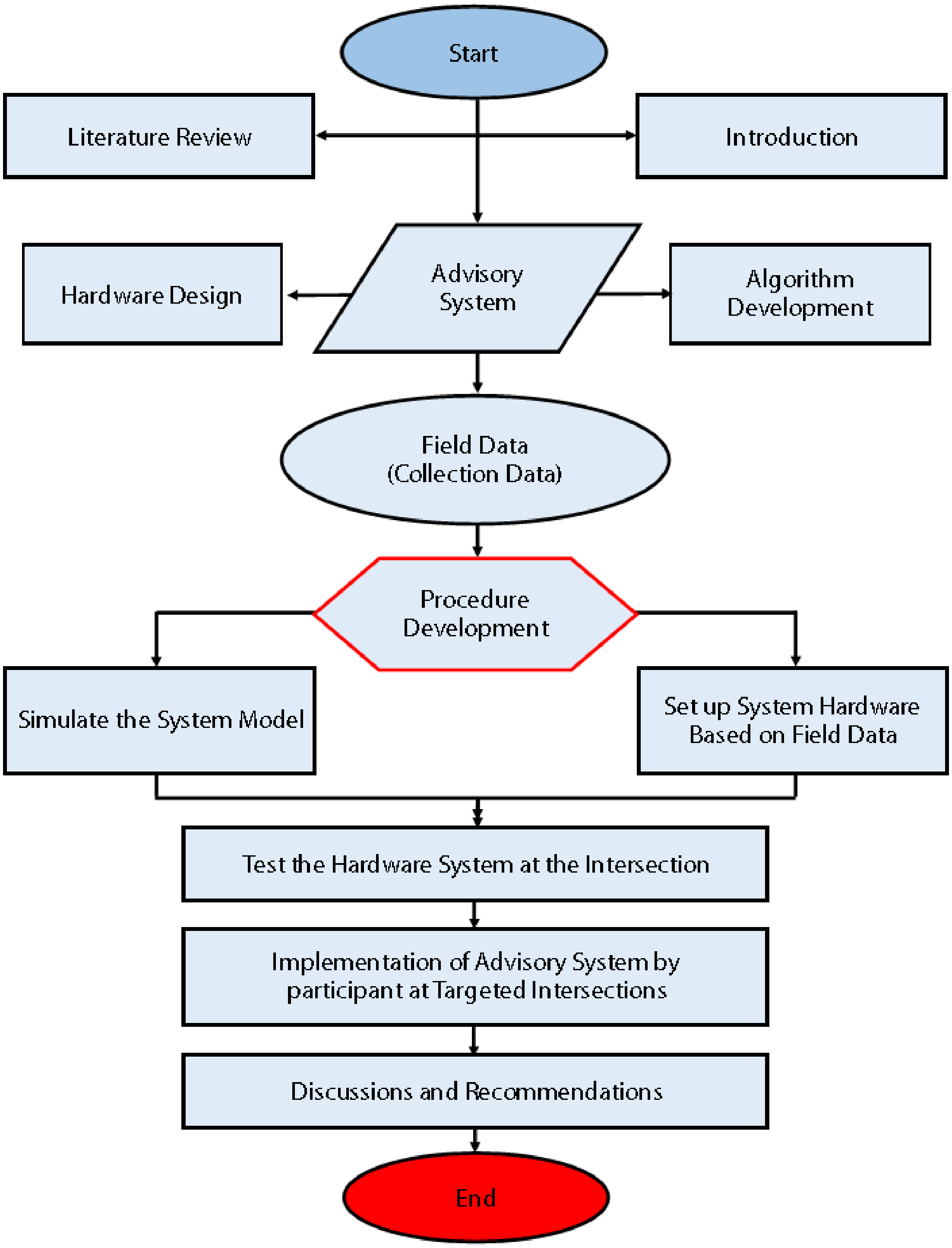

Figure I.5 – Research Methodology

II. LITERATURE REVIEW

A. Introduction

Over the next couple of decades, there will be a massive increase in the portion and number of older people in both developed and underdeveloped countries. Accordingly, Claire C et al. (2003) argue that there will be a substantial increase in the licensing rates of older drivers. This section represents an in-depth review of the problems old drivers face and how advanced technologies may be able to help the older drivers at intersections.

B. Old Drivers

For effective driving, a driver must possess sufficient motor, visual, and cognitive skills. A study by Romoser et al. (2013) discovered that when drivers cross the age of 70, they tend to get involved in more vehicle accidents, primarily in unsignalized intersections. This is because, with aging, older drivers suffer from increased distractibility, a substantial decrease in memory capacity, inability to remember particular scanning patterns, and head movements difficulty. According to Hu et al. (1998), concerns regarding the safety of older drivers arise from the fact that with ageing, they become vulnerable against sensory, motor, and cognitive deficits. Thus, it becomes difficult for older drivers to drive in bad weather, unfamiliar areas, intersections, and rush hours (Payyanadan, Lee, and Grepo, 2018).

At intersections, Boyle (2009) and Li et al. (2019) showed that older drivers perform fewer peripheral glances, make more search errors, and take longer mean fixation duration. Similarly, Yamani et al. (2016) used data acquired from the driving simulator to analyze the glance behavior and the capabilities of old age drivers to coordinate their eye and head movements while steering the vehicle at intersections. The results show that the inability of older drivers to effectively execute glances to the sides, when negotiating at intersections was less as compared to the middle-aged drivers. Dukic and Broberg (2012) discovered that due to limited neck flexibility, the scanning capabilities of older drivers are relatively lower than that of younger drivers. Stokes et al. (2000) found that around 28% of older drivers lack the ability to judge speeds correctly when entering an unsignalized intersection.

Yan, Radwan and Guo (2007) carried out an experiment using a driving simulator to examine the impacts of the age of driver and traffic speed on gap acceptance behavior. The study discovered a noticeable decline in driving performance with the increase in age. Unlike young drivers, older drivers struggle in properly judging, perceiving, and detecting gap safety (exemplified in Figure II.1). Zhou et al., (2017) found that older drivers are more likely to accept gaps based on the distance between the vehicles rather than the speed. Likewise, Davis and Swenson (2004) analyzed data of 74 drivers attempting to make left turn decisions at an intersection. The study discovered that drivers aged 56 or above had similar gap acceptance behavior – they tend to accept shorter time gaps than required for a safe roadway entry and not causing the approaching vehicles to significantly slow down.

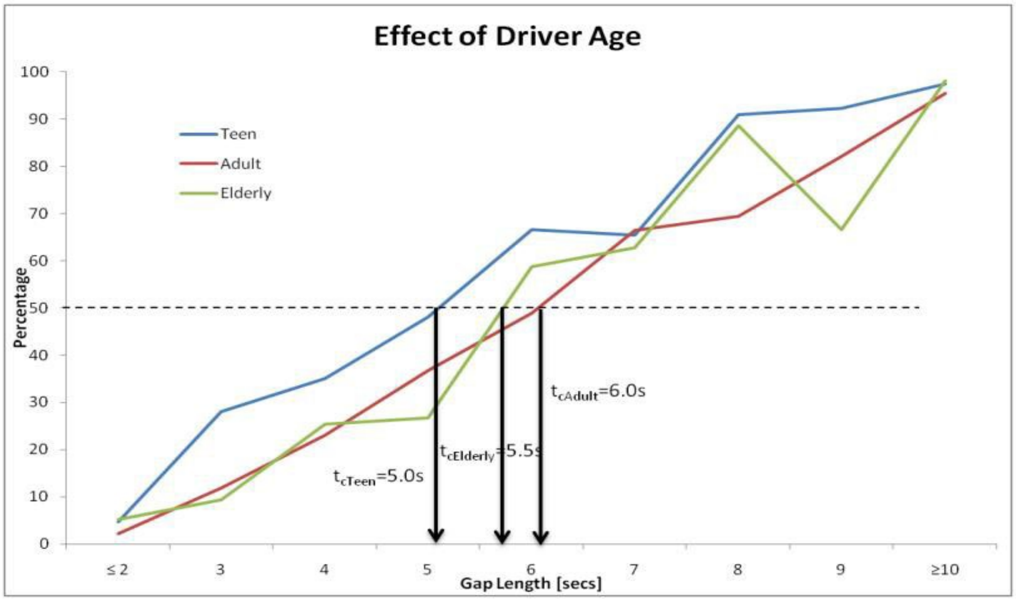

Figure II.1 - Gap Acceptance by Age (Tupper, Knodler Jr and Hurwitz, 2011)

C. Critical Gap and Influencing Factors

Critical gap as the minimum time interval in the traffic stream of the major road that enables the driver of the minor street vehicle to seek entrance (Dissanayake, Lu, and Yi, 2002). According to HCM, drivers generally accept gaps greater than the critical gap and reject those smaller than the critical gap.

Critical gap is an important factor in understanding drivers' gap acceptance behavior. According to Hewitt (1983), estimation of the critical gap is a challenging task that is usually done using accepted and rejected gaps. The following methods have been found to calculate the critical gap.

a. Raff's Method

Raff's method is one of the most popular methods that are used by the designers for the estimation of the critical gap. According to Lord-Attivor and Jha (2012), Raff's method sets the critical gap as the gap size where the number of accepted gaps equals that of the rejected gaps. Gavulová (2012) stated that the critical gap calculation through this method is very effective as it uses data that can be easily collected. Guo. (2010) claimed that the use of this method is very effective for the experts as it gives accurate results in conditions where the traffic flow is not very heavy.

b. Logit Method

The Logit method is one of the most complex and advanced methods for critical gap calculations. This method uses different factors like drivers' behavior and time delay to estimate the values of critical gaps. Thus, this method is highly effective in critical gap calculation as it allows the experts to consider the effect of the behavior of the drivers on the values of critical gaps. The Logit method is based on the use of the regression model for the calculation of the critical gap values (Amin and Maurya, 2015).

Ashalatha and Chandra (2011) mentioned that the use of the Logit method for the critical gap calculation of major and minor roads has various inefficiencies due to the complexity of the method. The involvement of the regression model makes this method lengthy and challenging.

c. Siegloch Method

Siegloch method is regarded as one of those methods that assist in calculating the critical gap on the basis of capacity. In particular, the method considers the total number of vehicles that pass through each gap in the main flow. This indicates that the method is only applicable to the bunched flow of the traffic (Guo, Wang, and Wang, 2014). Gattis and Low (1999) also supported this idea by claiming that to use the Siegloch method, the minor roads must be saturated with queued traffic.

Different factors may influence drivers' choice of the critical gap. Tupper, Knodler Jr, and Hurwitz (2011) found the number of gaps rejected, wait time of the driver, and the presence of large queue at the back of the driver may be most influential to gap acceptance (see Figures II.2, II.3, and II.4). These factors may prompt drivers to accept shorter gaps that could endanger their safety. Additional factors that influence gap acceptance, according to Dotzauer et al. (2015), include maturity, driving experience, maintaining attention on the road, effective searching capability, and hazards recognition.

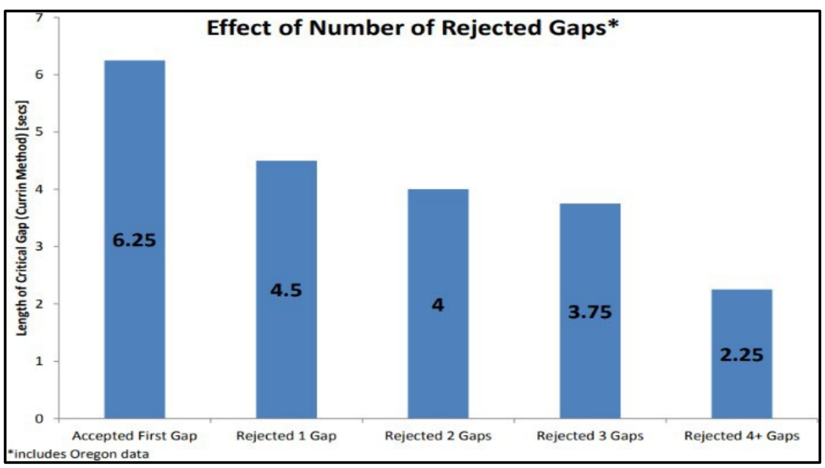

Figure II.2 - Effect of Number of Gaps Rejected on Gap Acceptance (Tupper, Knodler Jr and Hurwitz, 2011)

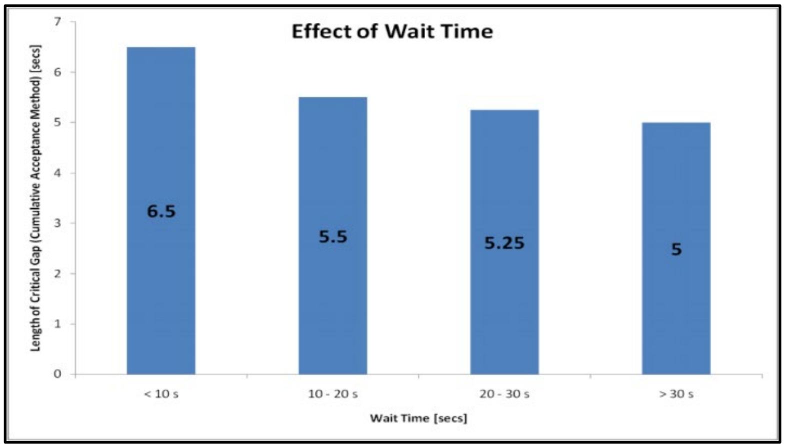

Figure II.3 - Wait Time Effect on Gap Acceptance (Tupper, Knodler Jr and Hurwitz, 2011).

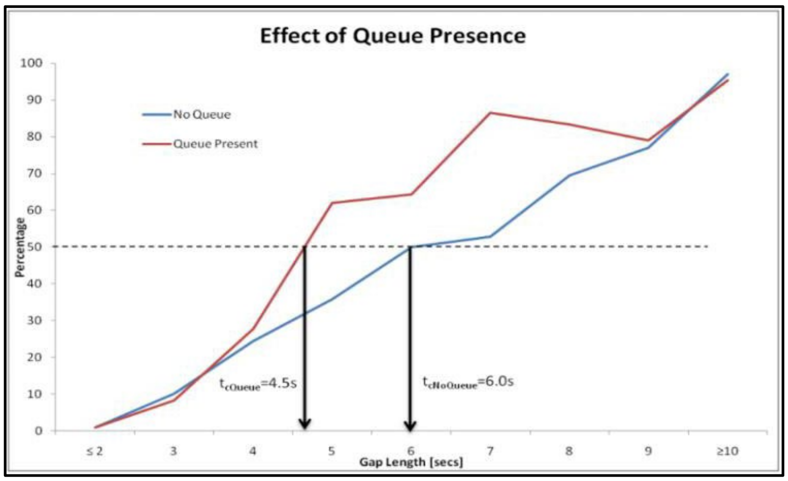

Figure II.4 - Queue Presence Effect on Gap Acceptance Behavior (Tupper, Knodler Jr and Hurwitz, 2011)

In addition to those influencing factors discussed above, numerous other studies also found that, for older drivers, darkness, traffic volume, approaching speed, and maneuver type also play a major role in gap acceptance decisions.

D. Assistance to Older Drivers in Vehicle Control and Gap Acceptance

Different intelligent infrastructure systems have been proposed to enhance traffic safety for older drivers. For instance, Frison et al. (2017) performed a user-centered process, which was composed of different methods, including UX-curves, think-aloud, driving simulator studies. The study discovered that the availability of connected vehicles could increase the performance of older drivers. Multiple other studies have addressed the relevance of connected vehicles for older drivers at unsignalized intersections. Frison et al. (2017) investigated the trust and acceptance of older drivers in connected vehicles and concluded that almost half of the older respondents displayed a positive attitude towards the concept.

Since older drivers tend to underestimate the arrival time of vehicles travelling at higher speed, Rusch et al. (2014) proposed the use of augmented reality cues to help older drivers in making an effective judgment when making left-turns. Tian, Morris and Libby (2018) proposed to use a Rural Intersection Conflict Warning System (RICWS) that provides motorists real-time traffic information to prevent fatal right-angle crashes and serious injuries. Chen and Liu (2017) developed a gap-based automated vehicular speed control algorithm that considers acceptable gaps, unacceptable gaps, running status of the targeted vehicle, and dynamic conditions of real-world traffic. With the help of this algorithm, the author proclaims that drivers, especially older drivers, can prevent potential conflicts at unsignalized intersections while simultaneously minimizing fuel consumption, vehicle emission, and travel time.

Different types of warnings and alerts may play a key role in helping drivers ensure safety. Arslan Yilmaz (2020) found that a Hazard System Warning based on different sounds can be used to warn drivers about possible hazardous traffic situations so that the chances of an accident are reduced. The study also found that the use of sounds in these hazard systems is more effective as compared to other forms of alerts such as lights. Yang et al. (2019) reveal that using in vehicle audio warnings can be very helpful in making the drivers aware of the possible dangers at intersection crossings.

In addition to the above, warning systems in vehicles can also work using different light alerts. The study by Yan et al. (2015) found that collision warning systems can be used to warn drivers about a possible collision with red lights. The red color can gain the attention of the drivers more effectively as compared to other colors. It was also noted during the study by Young et al. (2017) that older people have more difficulties in their visuals, which makes light warnings less effective. Dotzauer et al. (2015) highlighted that different warnings could be given to the driver about high speed, upcoming intersection, a vehicle changing lane, or any other possible danger. This form of an in-vehicle warning system can be very effective for older drivers to gain close attention to a specific problem while driving, which will also reduce the chances of accidents.

Finally, Bengler et al. (2014) reveal that the use of video-based driver assistance systems can prove to be helpful as well in guiding the drivers cross an intersection. Although these systems prove to be very effective for the other drivers, they might not be preferred by older drivers as they cannot focus on the road as well as on the video at the same time. The use of such a system, thus, might become a distraction for the older drivers, increasing the chances of accidents. Hence, it is one of the research objectives in this project to evaluate and compare older drivers' acceptance to different ways to present the warning messages.

III. ADVISORY SYSTEM HARDWARE DESIGN AND ALGORITHM DEVELOPMENT

A. Introduction

The most challenging driving task for older drivers is finding the appropriate safe gap to enter a major road from a minor road controlled by a stop sign. This problem can be effectively handled by using connected vehicle technologies.

This section covers detailed information about the new advisory system hardware, algorithm development, and how it works in different scenarios. This in-vehicle system provides a warning message about an unsafe gap to older drivers waiting at the minor road, discouraging them from accepting the gap. The unsafe gap is shorter than the shortest gap that older drivers can accept to make a safe maneuver. More discussion on the shortest gap determination will be provided in a later section.

To apply the warning system at an intersection, two types of vehicles are considered. The first type is that vehicles on major roads can communicate with other vehicles and the nearby infrastructure, and the second type is the ordinary vehicles, which represent most vehicles on the roadway today, not supported by data communications between vehicles and the infrastructure.

B. System Concept and Design

As mentioned above, the first type of vehicle represents a controlled situation where all vehicles involved have the ability to communicate with each other through V2V and the infrastructure via V2I. The second type represents an uncontrolled situation, where all vehicles on the major road have no connectivity with others, but the vehicles on the minor road (with older drivers) can communicate with the roadside warning system developed in this research. The following sections explain the design and intended application of the system in those two scenarios.

1. Controlled Situation

In a controlled situation, once the vehicle on a minor road is pulled up to the intersection, the in-vehicle component of the system starts requesting information from the central system located at the intersection. Then, the central system starts collecting information from vehicles on the major road and calculates gap distributions.

The vehicles on both the minor and major roads communicate with the infrastructure through the Data Acquisition Unit installed in the vehicles. This unit comprises a Liquid Crystal Display (LCD), UART Serial GPS module, a XBee Zigbee module, and a microcontroller. The GPS module is used to locate where the vehicle is relative to other vehicles and determine if a vehicle is in the intersection range to be included. The XBee Zigbee module is used for wirelessly communicating with other vehicles and receiving information about the distance and speed of the approaching vehicles. The microcontroller is used to run the different devices and make sure that they are doing what they're supposed to be doing in different situations. The intersection communicates with the vehicles on the minor and major roads through the central terminal (central system) installed at the intersection. This central terminal would consist of another XBee Zigbee module and a microcontroller. Along the road on each side of the intersection, there will be one XBee Zigbee relay. These relays serve the purpose of extending the XBee Zigbee module's effective range of data communication. The system layout and components are illustrated in Figure III.1.

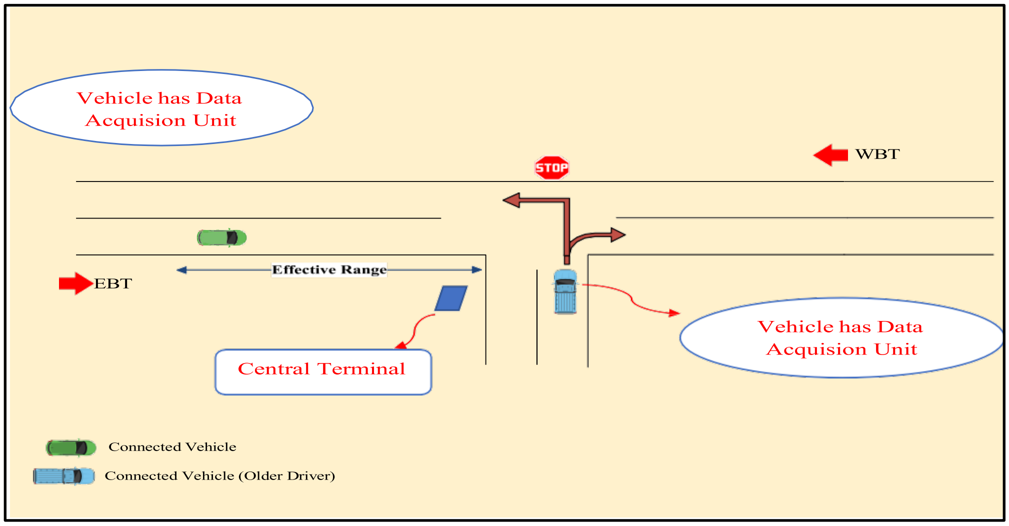

Figure III.1 - Controlled Situation System Components

When a vehicle on a minor road arrives at the intersection, the GPS module in the data acquisition unit inside the vehicle will begin checking the coordinates and if the vehicle is within the effective range of the intersection or not. If the vehicle is within the range, the data acquisition unit starts communicating wirelessly by XBee Zigbee to a central terminal at the intersection to inquire if or not a gap on the mainline is safe for a right or left turn.

When XBee Zigbee module in the central terminal receives the request from the data acquisition unit, the central terminal starts checking if there is a vehicle in an effective range (900 feet used in this project). If there are no vehicles, then no action is required. If there is a vehicle, then the XBee Zigbee module in the central terminal starts requesting information from the vehicle's data acquisition unit, including speed and distance from the intersection provided by the GPS module. The central terminal then starts calculating the gap and sending the results to the waiting vehicle data acquisition unit. The unit displays a warning message if the oncoming gap is not safe enough to make a turning movement. The entire process is illustrated in the flowchart next (Figure III.2).

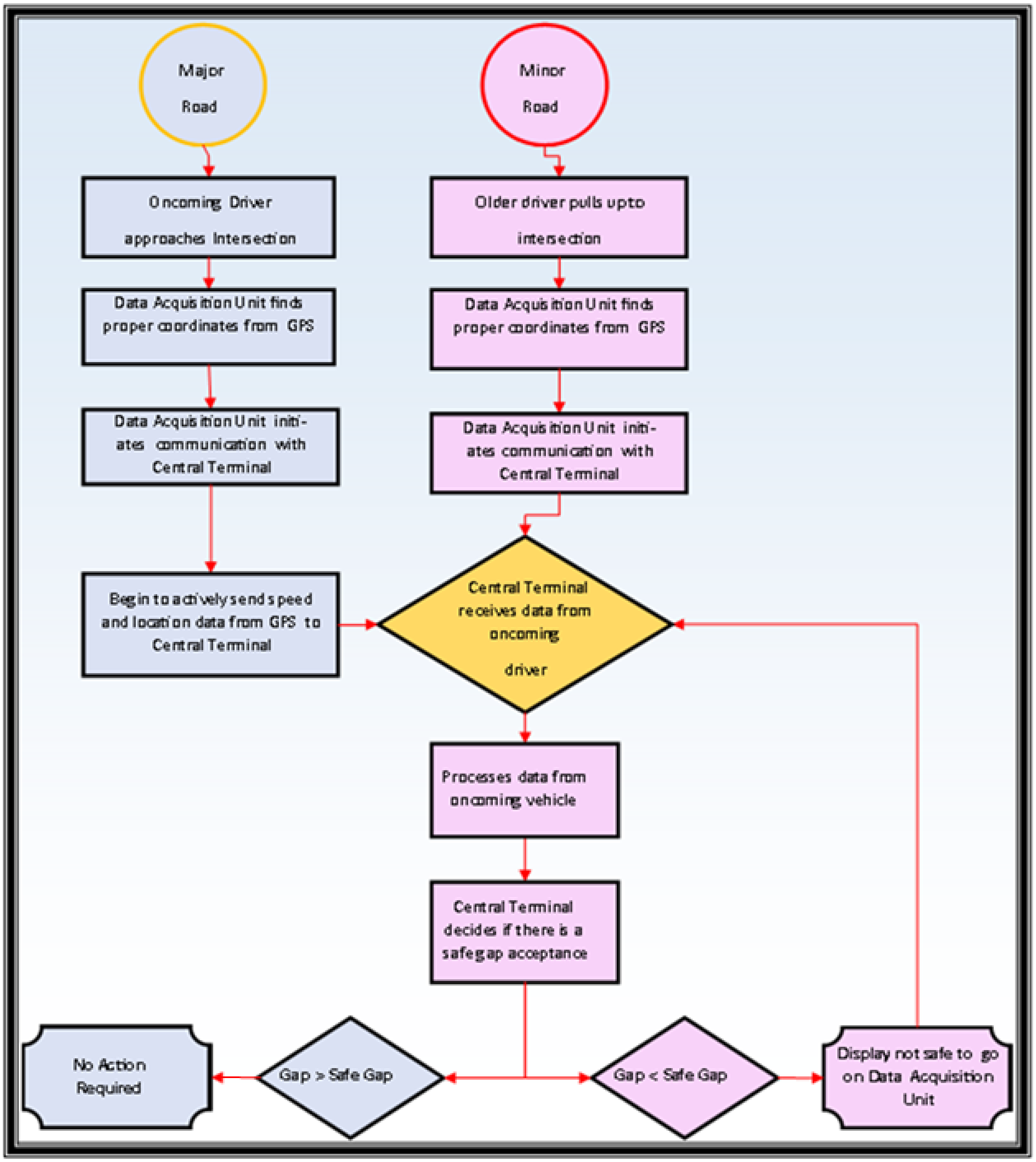

Figure III.2 - Controlled Situation Flow Chart

2. Uncontrolled Situation

In an Uncontrolled situation, the vehicles on the major road cannot communicate with other vehicles and the nearby infrastructure. There is no data acquisition unit installed in the vehicles on the major road. In this situation, installing external sensors on the major road to acquire information about oncoming vehicle's location and speed is necessary.

Once a vehicle in the minor road is pulling up to the intersection, it starts requesting information from the central system at the intersection. Then, the intersection infrastructure starts requesting information from the sensors on the major road. The vehicle on minor road communicates with the infrastructure through the Data Acquisition Unit installed in the vehicle. This unit is composed of an LCD display, a UART Serial GPS module, a XBee Zigbee module, and a microcontroller.

The GPS module is used to locate where the vehicle is relative to other vehicles and whether the vehicle is in the range of the intersection to begin the process of checking if the intersection now is safe to turn into. The XBee Zigbee module has been used for wirelessly communicating with the central terminal at the intersection. The microcontroller would be used to run the different devices and make sure that they are doing what they're supposed to be doing in different situations.

The central terminal communicates with the minor road vehicle and the sensors on the major roads. This terminal consists of another XBee Zigbee module and a microcontroller. The sensors in major roads are composed of ultrasonic modules to provide updated speed and distance data for oncoming vehicles on the major road and send the information to the central terminal via the XBee Zigbee module.

Along the roadway on both sides of the intersection, there is one XBee Zigbee Relay. These relays serve the purpose of extending the XBee Zigbee module's effective range of communication. The system components are illustrated in Figure III.3.

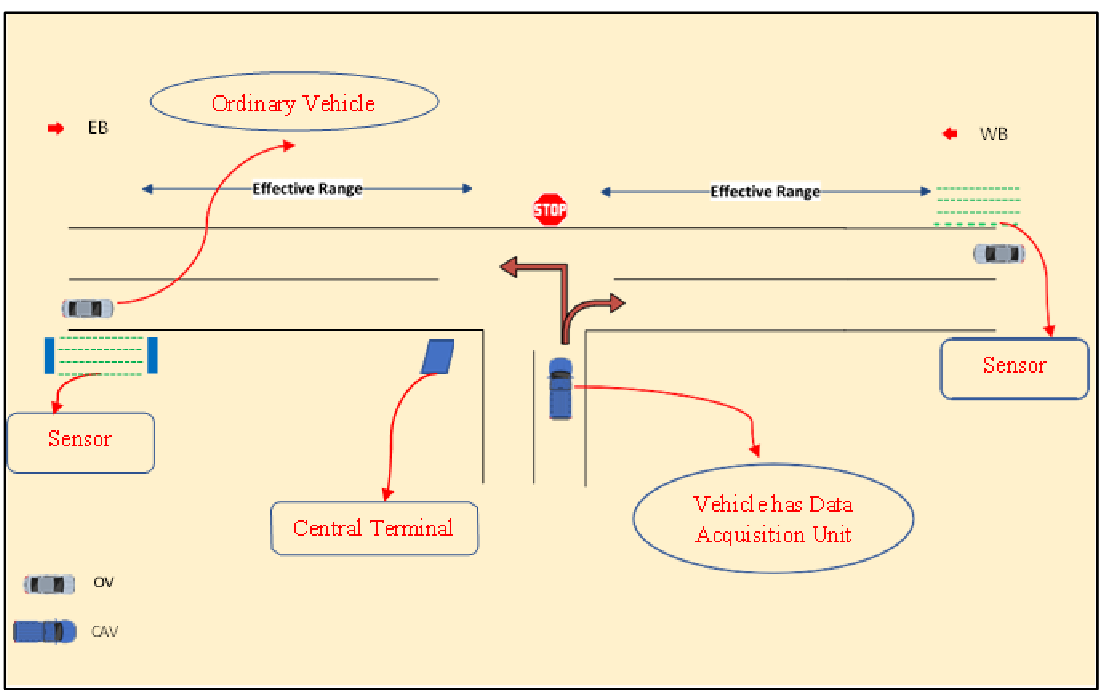

Figure III.3 - Uncontrolled Situation System Components

The central terminal received the request from the data acquisition unit in the minor road vehicle and starts communication wirelessly the with sensors on the major road. If there is no oncoming vehicle on the main road, no action is required. If there is a vehicle, the ultrasonic module on major road sends speed and location data to the data acquisition unit in the central terminal. The central terminal then starts calculating and analyzing the gap and send the decision to the waiting vehicle's data acquisition unit. The unit displays a warning message if the gap is unsafe to use, as illustrated in the flowchart (Figure III.4).

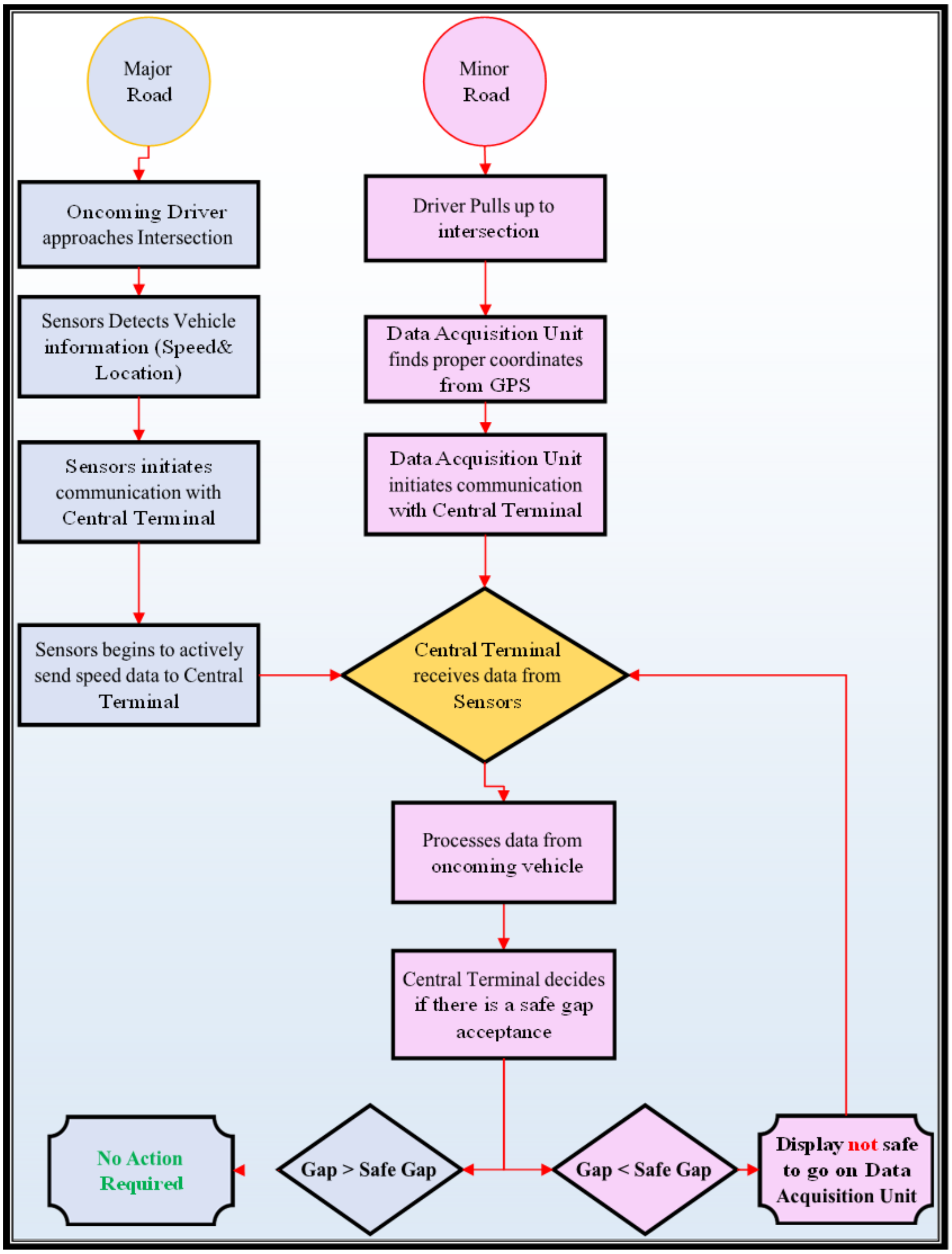

Figure III.4 - Uncontrolled Situation Flow Chart

C. Safe Gap Calculation

To calculate the actual gap in front of the oncoming vehicle, the system will receive the actual speed (V) and the actual distance between the vehicle and the intersection (D). Therefore, to find the gap time (GT), the system will use the following formula.

$$GT = \frac{D}{V}$$

For a safe gap to be used, it should be greater than the stopping sight distance (SSD) and the safe gap (GT_0).

$$GT > GT_0 > \text{SSD}$$

The stopping sight distance (SSD) is defined in A Policy on Geometric Design of Highways and Streets (2011) and it refers to the time needed for the driver in a major road to stop the vehicle safely if there is an obstacle on the road. The SSD consists of two parts; the first part is the reaction time, which is the driver's time needed to recognize an object on the road ahead until an action is taken to stop the vehicle, the second part is the time needed for the brakes to bring the vehicle to a complete stop. The SSD is smaller than the safe gap GT_0 used in this research, which includes an additional decision time for the older driver. GT_0 is determined from field data calibration, and it is discussed in a later section. The system will calculate the SSD for two reasons. First, to make sure that the vehicle on the major road has enough time to stop the vehicle when the older driver's vehicle enters the intersection. Second, if the major road vehicle's speed is very high, the system will use this information to remind the waiting vehicle on minor roads about the situation.

$$SSD\ (ft) = \text{V(PRT)} + \frac{\text{V}^2}{2\text{g}\ (\text{f} + \text{s})}$$

Where:

s = 0 slope of roadway

PRT: perception response time

f= friction of roadway surface

g = gravity constant

v = speed of major road vehicle

D. Implementation

The minor road vehicle waiting for a safe gap can make two possible choices, turning right and join eastbound traffic (EBT) or turning left to cross EBT and join westbound traffic (WBT). The algorithm for gap determination is different for the two scenarios.

1. Right Turn Scenario

When the older driver's vehicle comes to the minor road approach, waiting to make a right turn, it needs a gap larger than the SSD. The system will calculate the gap based on the speed and distribution of vehicles on the major road in the EBT. The situation of having none, one, or more vehicles is listed in Table III-1. The flowchart in Figure III.5 illustrates the system control logic for the right turning vehicle.

Table III-1 Right Turn Scenario

Right Turn Scenarios	
Scenarios	**No. of Vehicles in EBT**
Scenario 1	0
Scenario 2	1
Scenario 3	2

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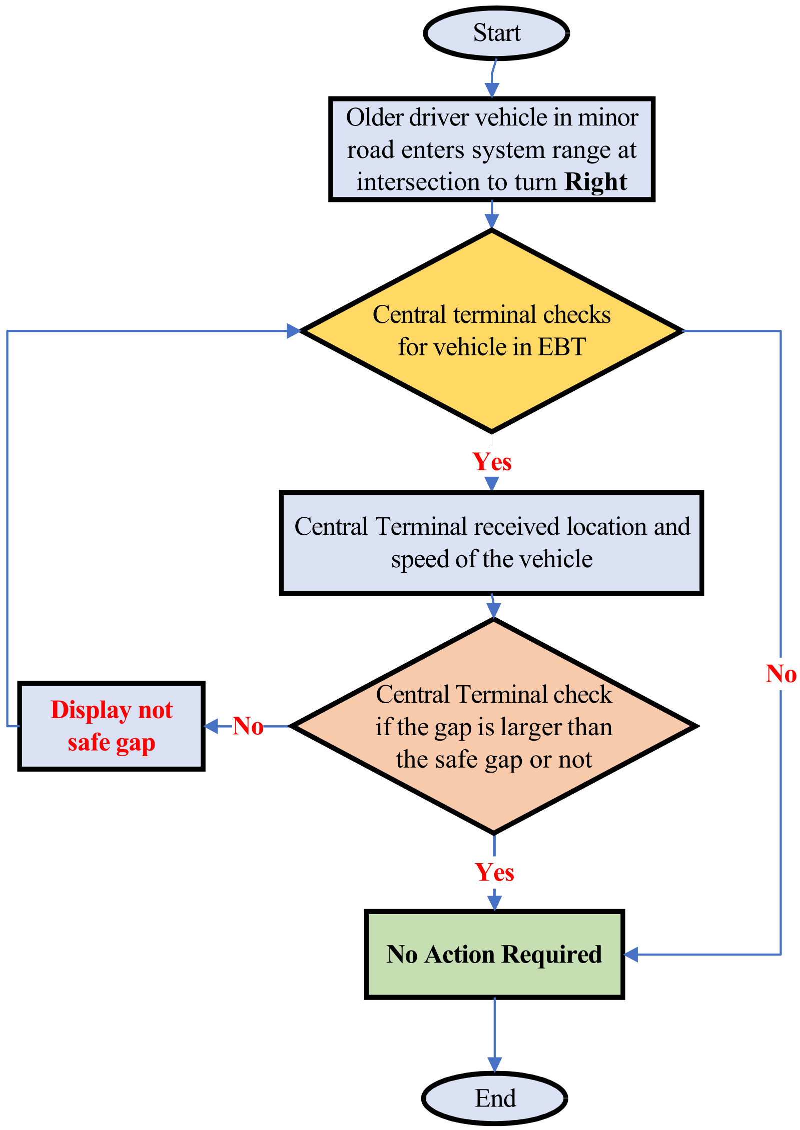

Figure III.5 - Right Turn Control Logic

a. No vehicles in EBT in the System Range
   If no vehicles in EBT can be found in the system range and an older driver vehicle is waiting on the minor road, no action is required because there is no potential conflict, as shown in Figure III.6.

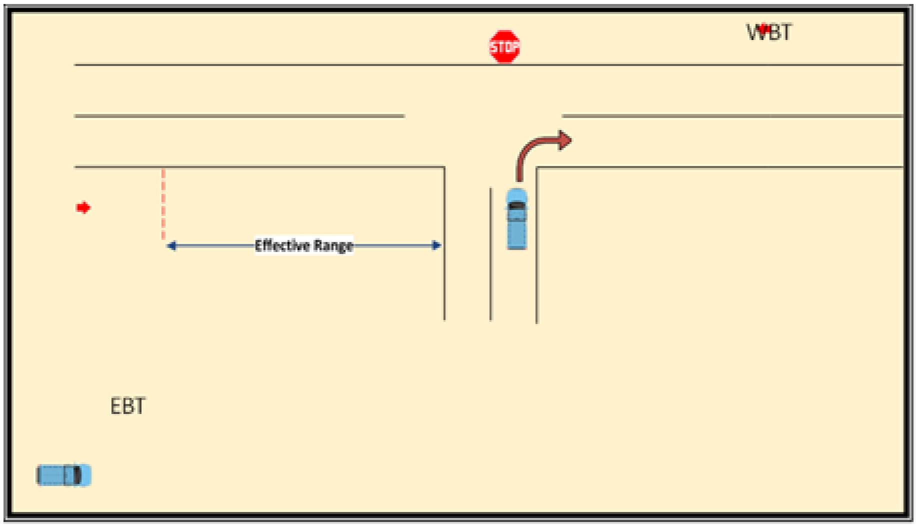

Figure III.6 - No EBT Vehicle, Older Driver Vehicle at Minor Road for Turning Right

b. One Vehicle in EBT in the system range
   There is only one vehicle in EBT in the system range and the older driver vehicle is waiting on the Minor Road, as shown in Figure III.7. A simple gap time is calculated.

$$GT_1 = \frac{D_1}{V_1}$$

Where:

D_1: Distance to the intersection for the vehicle in EBT
V_1: Vehicle speed in EBT

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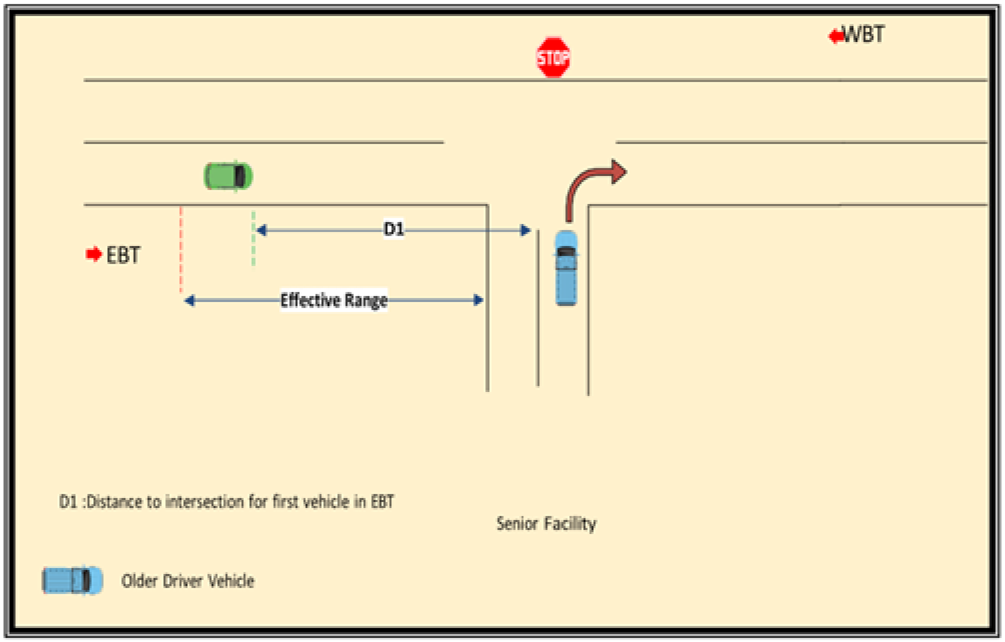

Figure III.7 - One Vehicle in EBT, Older Driver Vehicle at Minor Road for Turning Right

If gap (GT1) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then no action is required.

$$GT_1 > GT_0 > SSD_1$$

If the gap (GT_1) is smaller than SSD_1 or the safe gap (GT_0), the display in the older driver vehicle shows a warning message that it is not safe to go.

$$\mathrm{SSD1} < GT_1 < GT_0$$

c. Two Vehicles in EBT in the system range

If two vehicles in EBT are in the system range and an older drivers vehicle is waiting on the Minor Road, as shown in Figure III.8, the following calculations are made.

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

Where:

D_1: Distance to the intersection for the first vehicle in EBT
V_1: First vehicle speed in EBT
D_2: Distance to the intersection for the second vehicle in EBT

V_2: Second vehicle speed in EBT
GT_1: Gap for the first vehicle in EBT
GT_2: Gap for the second vehicle in EBT
SSD_1: The first vehicle stopping sight distance
SSD_2: Second vehicle stopping sight distance

If gap (GT1) is larger than safe gap (GT_0), and larger than the stopping sight distance (SSD_1), no action is required.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1), the display unit inside the older driver vehicle will show that it is not safe to go. As a result, the system will track the first vehicle and start to follow the movement of the second vehicle after the latter enters the system range. until it passes the intersection. Then, the system will start to check and estimate the gap in front of the second vehicle (GT_2) in EBT, as shown in Figure III.8

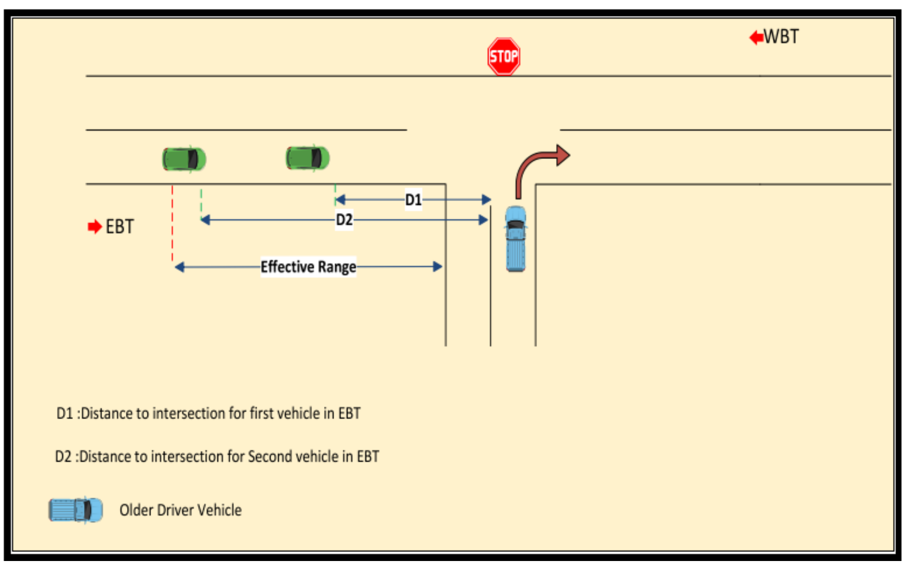

Figure III.8 – Two Vehicles in EBT, Older Driver Vehicle at Minor Road for Turning Right

If gap ($GT_2 – GT_1$) is larger than safe gap (GT_0) and the stopping sight distance (SSD_2), no action is required.

$$(GT_2 – GT_1) > GT_0 > SSD_2$$

If gap (GT_2) is smaller than safe gap (GT_0) or smaller than SSD_2, then the display unit inside the older driver vehicle will continue to show that it is not safe to go. In a similar way, the system will continue to check the position and speed of the next vehicle, and turn off the warning message until a safe gap is found.

2. Left Turn Scenario

When the older driver vehicle arrives at the intersection, wait for a gap to make a left turn, the system will calculate the gap based on the vehicles on the major road in both EBT and WBT.

The left turn scenario is much more complicated than the right turn scenario because the system will check for large gaps in EBT first and then in WBT. Each time the system fails to find a gap larger than the safe gap, whether in EBT or in WBT, it will display a warning message for the older driver and continue to search for a gap larger than the safe gap. The possible combinations of vehicle arrivals in EBT and WBT is shown in Table III-2.

Table III-2 Left Turn Scenarios

Left Turn Scenarios		
Scenarios	No. of Vehicles in EBT	No. of Vehicles in WBT
Scenario 1	0	0
Scenario 2	1	0
Scenario 3	2	0
Scenario 4	0	1
Scenario 5	0	2
Scenario 6	1	1
Scenario 7	1	2
Scenario 8	2	1
Scenario 9	2	2

The flowchart in Figure III.9 illustrated how the system control logic works for the left turn and the details for each scenario are explained below.

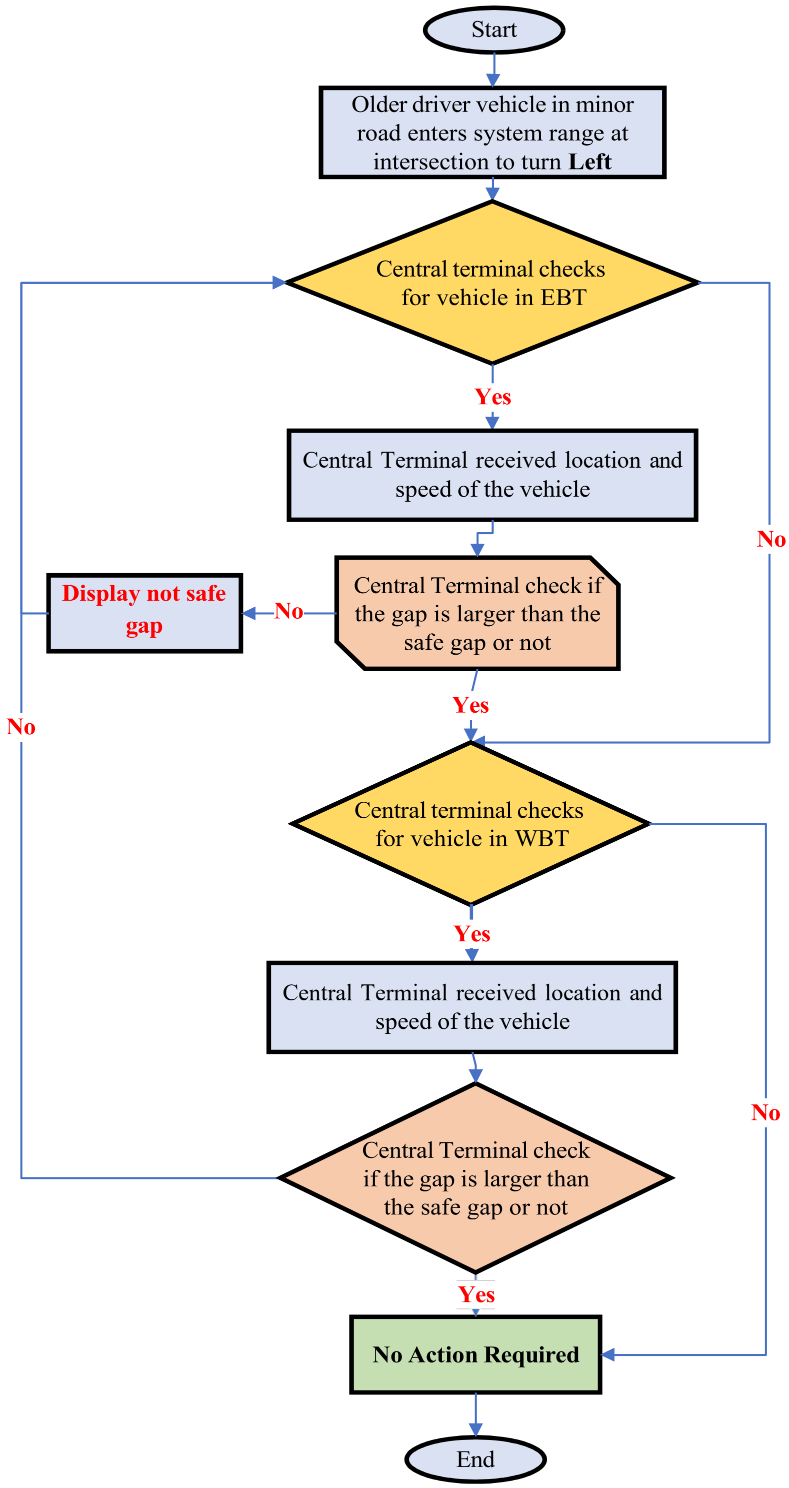

Figure III.9 - Left Turn Control Logic

a. No Vehicles in EBT and no Vehicles in WBT

No Vehicles in EBT and WBT in the system range, and there is an older driver vehicle, waiting on the minor road to turn left, as shown in Figure III.10.

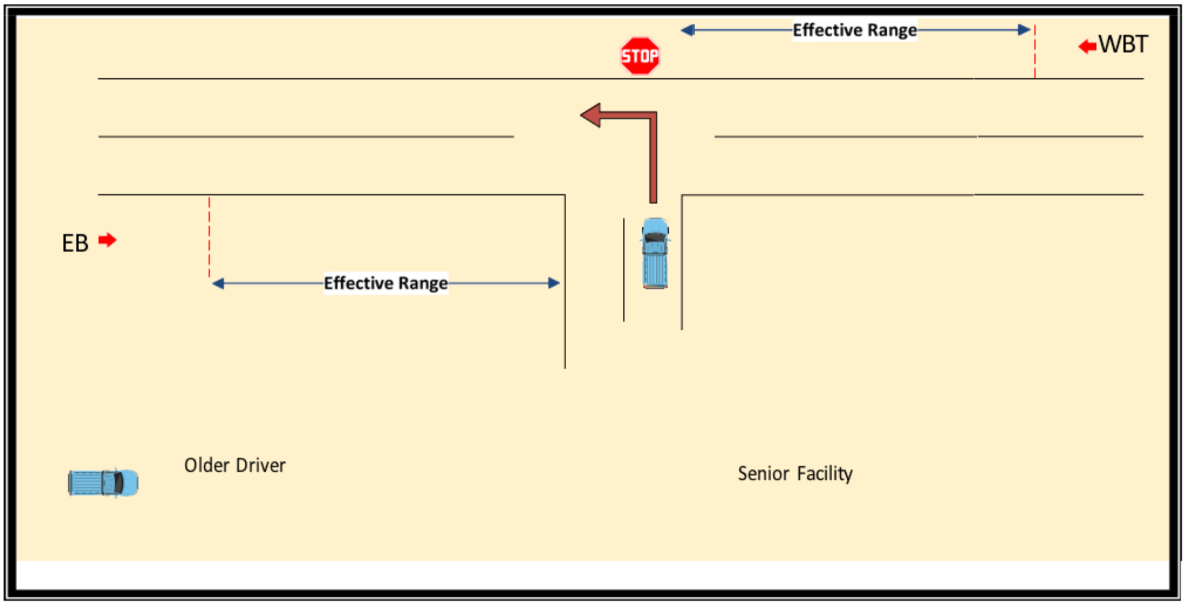

Figure III.10 - No Vehicles in EBT and WBT, Older Driver Vehicle at Minor Road to Turn Left

No action is required because there are no vehicle movement conflicts on EBT and WBT.

b. There are no vehicles in EBT and there is one vehicle in WBT

There are no vehicles in EBT in the system range, and there is one vehicle in WBT in the system range, and there is an older driver vehicle, waiting on the minor road, as shown in Figure III.11. The simple gap is calculated as follows.

$$GT_1 = \frac{D_1}{V_1}$$

Where:

D_1: Distance to the intersection for the first vehicle in WBT

V_1: Vehicle speed in WBT

SSD_1: First vehicle's stopping sight distance in WBT

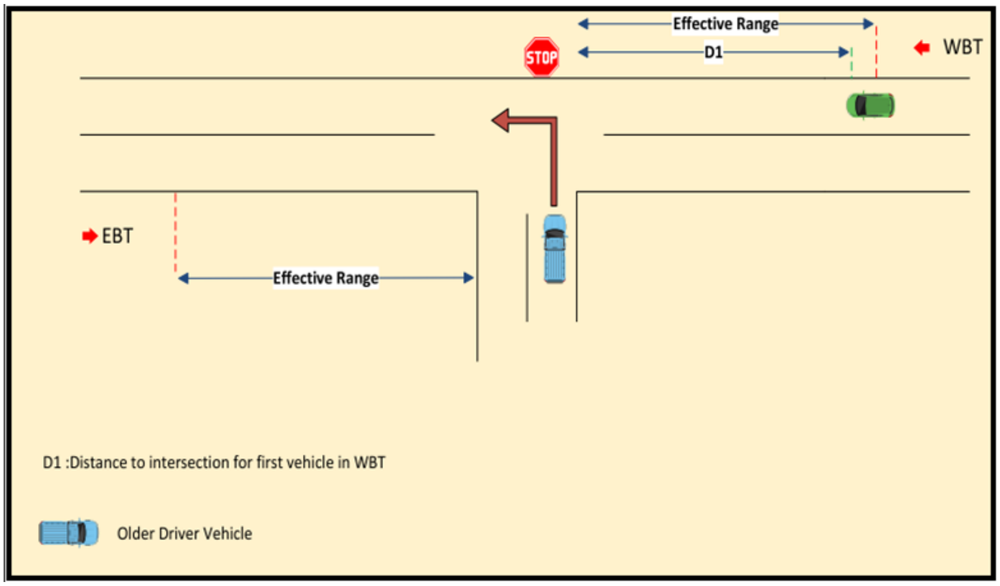

Figure III.11 - No Vehicles in EBT and One Vehicle in WBT, and Older Driver Vehicle at Minor Road Turning Left

If gap (GT1) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then no action is required.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT1) is smaller than safe gap (GT_0) or smaller than SSD_1, then the display unit inside the older driver vehicle will show that it is not safe to go. The system will track this vehicle until it passes the intersection and then recheck in EBT and WBT until a gap larger than the safe gap is found.

$$GT_1 < GT_0 < SSD_1$$

c. No Vehicles in EBT and there are Two Vehicles in WBT

No Vehicles in EBT in the system range and two vehicles in WBT are found, and there is an older driver vehicle waiting on the minor road to turn left, as shown in Figure III.12.

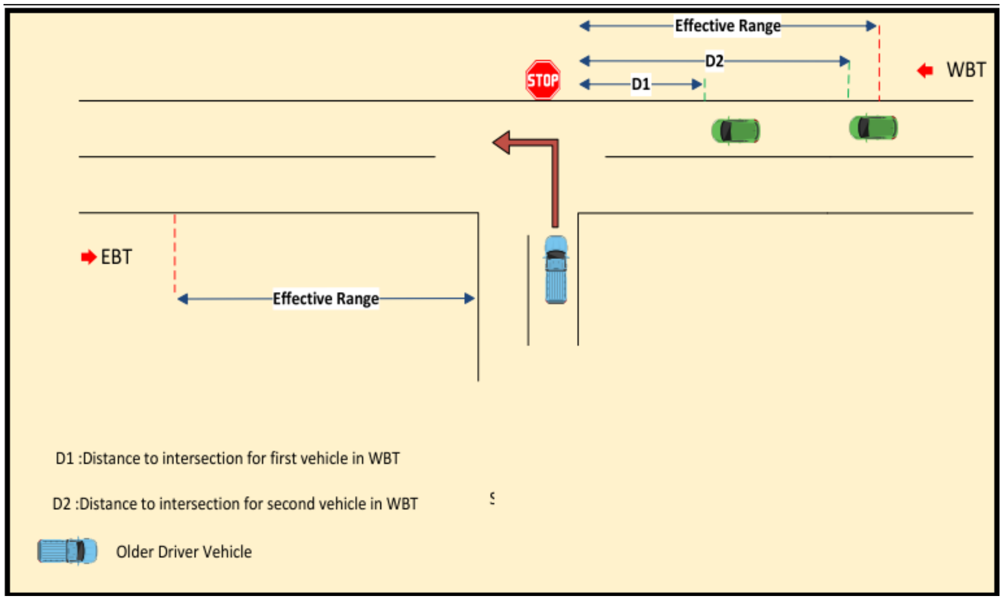

Figure III.12 - No Vehicles in EBT and Two Vehicles in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

Where:

D_1: Distance to the intersection for the first vehicle in WBT
V_1: First vehicle speed in WBT
GT_1: Gap for the first vehicle in WBT
GT_2: Gap for the second vehicle in WBT
SSD_1: Stopping sight distance for the first vehicle in WBT
SSD_2: Stopping sight distance for the second vehicle in WBT

If gap (GT1) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then no action is required.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT1) is smaller than safe gap (GT_0) or smaller than SSD_1, then the system will be tracking the first vehicle and start to follow the second vehicle for GT_2 in WBT.

If gap (GT_2) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_2), then no action is required.

$$GT_2 > GT_0 > SSD_2$$

However, If gap ($GT_2 – GT_1$) is smaller than safe gap (GT_0) or smaller than SSD_2, then the system inside the older driver vehicle will display that it is not safe to go. The system will continue to track the next vehicle for its gap with the preceding vehicle until a large enough gap is found before turning off the warning message.

$$(GT_2 – GT_1) > GT_0 > SSD_2$$

d. One Vehicle in EBT and no Vehicles in WBT

One vehicle in EBT in the system range and no vehicles in WBT are found and there is an older driver vehicle waiting on the minor road to make a left turn, as shown in Figure III.13.

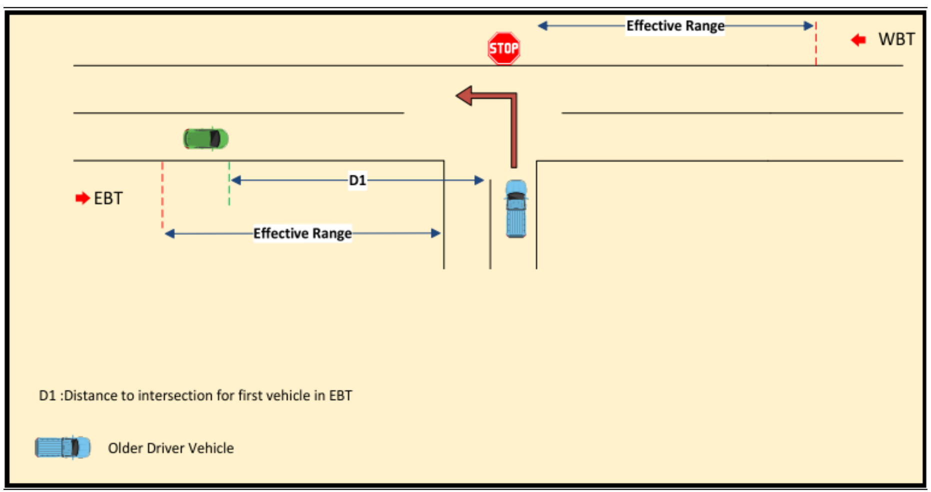

Figure III.13 - One Vehicle in EBT and No Vehicles in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

Where:

D_1: Distance to the intersection for the vehicle in EBT

V_1: Vehicle speed in EBT

SSD_1: Stopping sight distance for the first vehicle in EBT

If gap (GT1) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then no action is required.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1), then the in-vehicle display warns the older driver that it is not safe to go. The system will track this vehicle until it passes through the intersection and then recheck in EBT and WBT until a gap larger than the safe gap is found.

$$GT_1 < GT_0 < SSD_1$$

e. One Vehicle in EBT and One Vehicle in WBT

One Vehicle in EBT in the system range and one vehicle in WBT is found and an older driver vehicle is waiting on the minor road, as shown in Figure III.14.

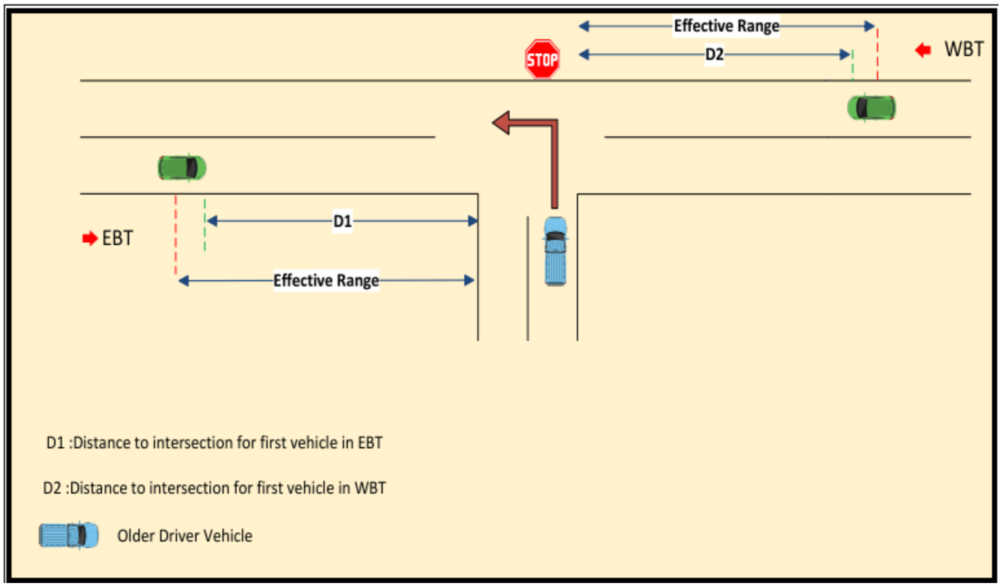

Figure III.14 - One Vehicle in EBT and One Vehicle in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

Where:

D_1: Distance to the intersection for the vehicle in EBT

V_1: Vehicle speed in EBT

D_2: Distance to the intersection for the vehicle in in WBT

V_2: Vehicle speed in WBT

SSD_1: Stopping sight distance for the first vehicle in EBT

SSD_2: Stopping sight distance for the first vehicle in WBT

If gap (GT1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1), then the display inside the older driver vehicle will show a message that it is not safe to go.

If gap (GT1) in EBT is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then the system will also need to check the gap (GT_2) in WBT.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT_2) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_2), then the display inside the older driver vehicle will show that it is not safe to go, regardless of the GT_1 duration.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 < GT_0 < SSD_2$$

If both gap (GT_1) in EBT and GT2 in WBT are larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1) and (SSD_2), then no action is required.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 > GT_0 > SSD_2$$

f. One Vehicle in EBT and Two Vehicles in WBT

One vehicle in EBT in the system range and two vehicles in WBT are found, and an older driver vehicle is waiting on the Minor Road to make a left turn, as shown in Figure III.15.

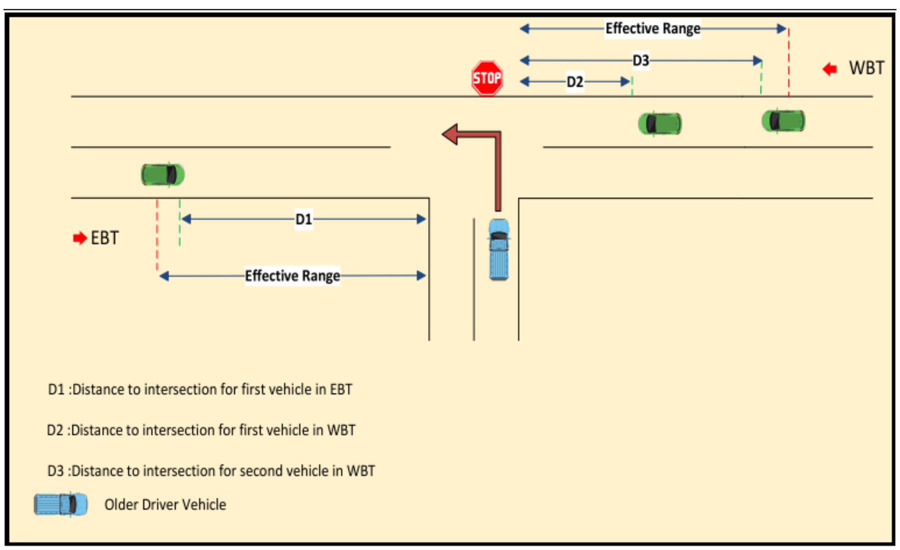

Figure III.15 - One Vehicle in EBT and Two Vehicles in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

$$GT_3 = \frac{D_3}{V_3}$$

Where:

D_1: Distance to the intersection for the first vehicle in EBT
V_1: First vehicle speed in EBT
D_2: Distance to the intersection for the first vehicle in WBT
V_2: First Vehicle speed in WBT
D_3: Distance to the intersection for the second vehicle in WBT
V_3: Second Vehicle speed in WBT
SSD_1: Stopping sight distance for the first vehicle in EBT
SSD_2: Stopping sight distance for the first vehicle in WBT
SSD_3: Stopping sight distance for the second vehicle in WBT

If gap (GT_1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1), then the display unit inside the older driver vehicle will display it is not safe to go.

$$GT_1 < GT_0 < SSD_1$$

If gap (GT_1) in EBT is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then the system will continue to check the size of gap (GT_2) in front of the first vehicle in WBT.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT_2) in WBT is also larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_2), then no action is required.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 > GT_0 > SSD_2$$

If gap (GT_1) in EBT is larger than the safe gap (GT_0) and larger than the stopping sight distance (SSD_1), but the gap (GT_2) in WBT is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_2),

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 < GT_0 < SSD_2$$

then the display inside the older driver vehicle will show a message that it is not safe to go. Next, the system will be tracking the EBT vehicle as well as the second vehicle (GT_3) in WBT. If gap (GT_3) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_3) the display unit inside the older driver vehicle will show that it is not safe to go.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_3 < GT_0 < SSD_3$$

If gap (GT_3) is larger than safe gap (GT_0) and SSD_3, then no action is required.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_3 > GT_0 > SSD_3$$

g. Two Vehicles in EBT and No Vehicles in WBT

Two vehicles in EBT in the system range and no Vehicles in WBT are found, and an older driver vehicle is waiting on the minor road to make a left turn, as shown in Figure III.16.

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

Where:
D_1: Distance to the intersection for the first vehicle in EBT
V_1: First vehicle speed in EBT
D_2: Distance to the intersection for the second vehicle in EBT
V_2: Second vehicle speed in EBT
GT_1: Gap for the first vehicle in EBT
GT_2: Gap for the second vehicle in EBT
SSD_1: Stopping sight distance for the first vehicle in EBT
SSD_2: Stopping sight distance for the second vehicle in EBT

If gap (GT_1) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then no action is required.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT_1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1) then the display unit inside the older driver vehicle will display it is not safe to go. Next, the system starts to check the gap for the second vehicle (GT_2) in EBT. If gap (GT_2) is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_2) and no vehicles in WBT, then the warning message on the display is removed.

$$GT_2 > GT_0 > SSD_2$$

However, if gap (GT_2) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_2) then the displayed warning message will remain unchanged unit an acceptable gap is found/

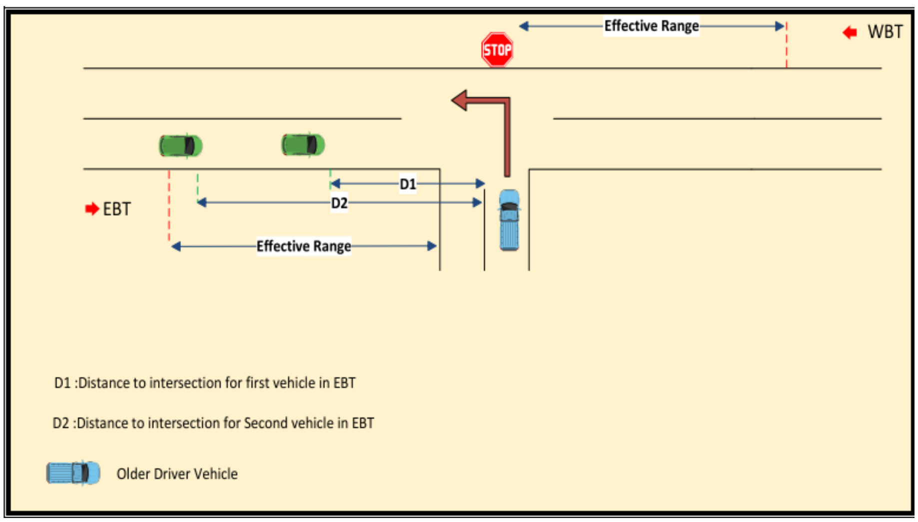

Figure III.16 - Two Vehicles in EBT and No Vehicles in WBT, Older Driver Vehicle at Minor Road, Turning Left

h. Two Vehicles in EBT and One Vehicle in WBT

Two vehicles in EBT in the system range and one vehicle in WBT is found, and an older driver vehicle is waiting on the Minor Road to make a left turn, as shown in Figure III.17.

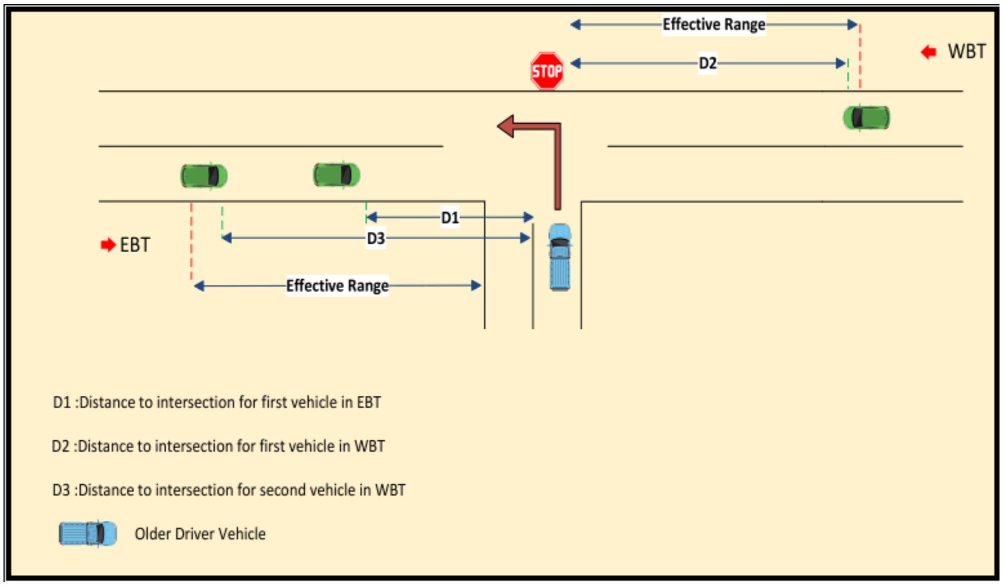

Figure III.17 - Two Vehicles in EBT and One Vehicle in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

$$GT_3 = \frac{D_3}{V_3}$$

Where:
D_1: Distance to the intersection for the first vehicle in EBT
V_1: First vehicle speed in EBT
D_2: Distance to the intersection for the first vehicle in WBT
V_2: First Vehicle speed in WBT
D_3: Distance to the intersection for the second vehicle in EBT
V_3: Second Vehicle speed in EBT
SSD_1: Stopping sight distance for the first vehicle in EBT
SSD_2: Stopping sight distance for the first vehicle in WBT
SSD_3: Stopping sight distance for the second vehicle in EBT

If gap (GT_1) in EBT is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), then the system will check the gap (GT_2) in front of the first vehicle in WBT.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT_1) in EBT is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_1), and the gap (GT_2) in WBT is also larger than safe gap (GT_0) and the stopping sight distance (SSD_2), then no action is required.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 > GT_0 > SSD_2$$

If gap (GT1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1) then the display unit inside the older driver vehicle will show a message that it is not safe to go.

Then, the system start check about the gap for the second vehicle (GT_3) in EBT.
If gap (GT_3) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_3), the display unit inside the older driver vehicle will continue to show it is not safe to go.

$$GT_3 < GT_0 < SSD_3$$

On the other hand, if gap (GT_3) in EBT is larger than safe gap (GT_0) and larger than the stopping sight distance (SSD_3), and there is a gap larger than safe gap (GT_0) and the stopping sight distance (SSD) in WBT, the warning message will be removed from the display board.

i. Two Vehicles in EBT and Two Vehicles in WBT

Two vehicles in EBT in the system range and two vehicles in WBT are found, and an older driver vehicle is waiting on the minor road to make a left turn, as shown in Figure III.18.

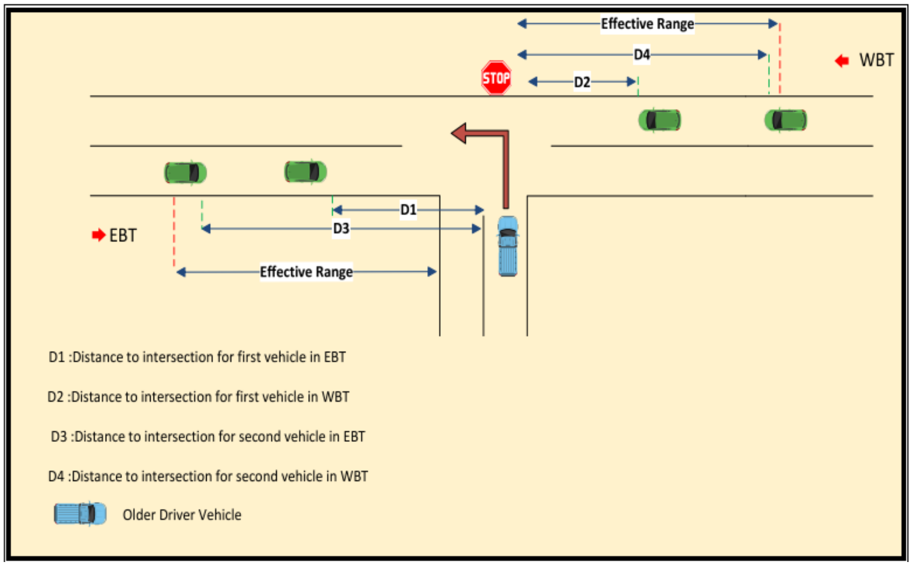

Figure III.18 - Two Vehicles in EBT and Two Vehicles in WBT, Older Driver Vehicle at Minor Road, Turning Left

$$GT_1 = \frac{D_1}{V_1}$$

$$GT_2 = \frac{D_2}{V_2}$$

$$GT_3 = \frac{D_3}{V_3}$$

$$GT_4 = \frac{D_4}{V_4}$$

Where:
D_1: Distance to the intersection for the first vehicle in EBT
V_1: First Vehicle speed in EBT
D_2: Distance to the intersection for the first vehicle in WBT
V_2: First Vehicle speed in WBT
D_3: Distance to the intersection for the second vehicle in EBT
V_3: Second Vehicle speed in EBT
D_4: Distance to the intersection for the second vehicle in WBT
V_4: Second Vehicle speed in WBT
SSD_1: Stopping sight distance for the first vehicle in EBT
SSD_2: Stopping sight distance for the first vehicle in WBT
SSD_3: Stopping sight distance for the second vehicle in EBT

SSD_4: Stopping sight distance for the second vehicle in WBT

If gap (GT_1) in EBT is larger than safe gap (GT_0) and the stopping sight distance (SSD_1), then the system will check the gap (GT_2) in front of the first vehicle in WBT.

$$GT_1 > GT_0 > SSD_1$$

If gap (GT_2) in WBT is also larger than safe gap (GT_0) and the stopping sight distance (SSD_2), then no action is required.

$$GT_1 > GT_0 > SSD_1 \text{ and } GT_2 > GT_0 > SSD_2$$

But if gap (GT1) is smaller than safe gap (GT_0) or smaller than the stopping sight distance (SSD_1), then the display unit inside the older driver vehicle will show it is not safe to go.

$$GT_1 < GT_0 < SSD_1$$

Then, the system will start to check about the gap for the second vehicle (GT_3) in EBT. If gap (GT_3) is smaller than safe gap (GT_0) or the stopping sight distance (SSD_3), then the warning message inside the older driver vehicle will remain displayed.

$$GT_3 < GT_0 < SSD_3$$

If gap (GT_3) in EBT is larger than safe gap (GT_0) and the stopping sight distance (SSD_3), Then, the system starts to check about the gap at the WBT.

$$GT_3 > GT_0 > SSD_3$$

If there is a gap larger than the safe gap (GT_0) $in\ WBT$. Then, the warning message will be removed.

When there are more than 2 vehicles in each direction, this system will continue to check, one after another, using the above-described algorithm to display a warning message whenever a gap is found unsafe for entering the intersection. This system keeps checking through vehicles on the major road every 0.1 seconds and sending all information to the central terminal at the intersection. It should be noted that the central terminal will only send the information to the older driver waiting at the intersection about unsafe gaps; it is up to the older driver to decide if or not to accept the system advice or rejected it.

IV. SITE for FIELD TEST

A. Introduction

This research investigates older drivers' gap selections from a minor road by focusing on traffic safety concerns and impact on operational efficiency at T intersections controlled by stop signs. At this type of intersection, traffic on the minor road must yield to traffic on the major road, so a driver on the minor road, waiting to join the major road, must seek a safe gap between oncoming vehicles on the major road, as shown in Figure IV.1.

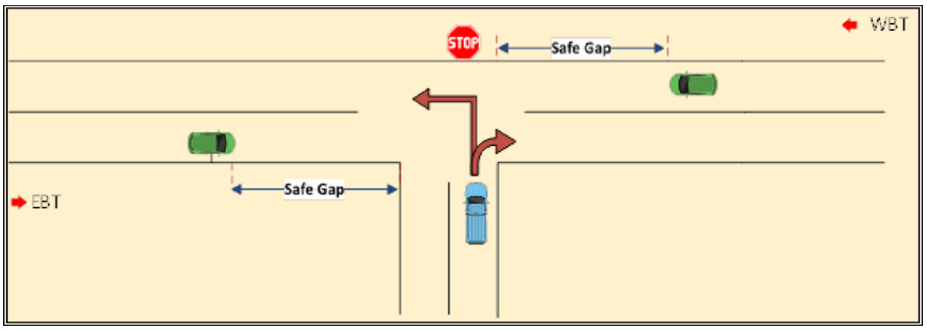

Figure IV.1 - Unsignalized T intersection

The field test investigates the feasibility of the system when used by older drivers in real traffic conditions. The experiment has been conducted at two stop sign controlled T intersections in Summit County. In a two-step process, we first examined how older drivers selected gaps before using the warning system and established the critical gap in the targeted intersections, and then compared the results after using the warning system, as shown in Figure IV.2.

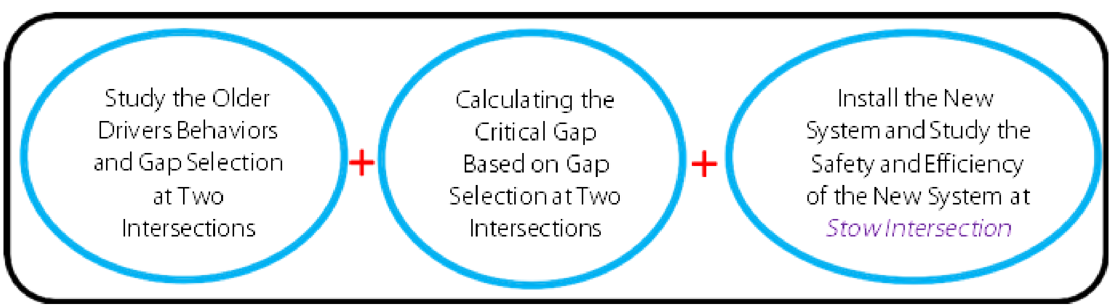

Figure IV.2 - Field Test Flowchart

B. Site Selection

In this project, several factors were considered in choosing the site locations to collect accurate field data. The first factor is the intersection geometry, because it potentially impacts the gap acceptance behavior due to sight distance and grades. In addition, volume, speed, number of older drivers are also important factors. While an unclear sight distance to lead to poor gap selection, locations having visible horizontal curves and vertical grades were avoided. It is also important to ensure that the volumes in major and minor roads are large enough so that there are a sufficient number of vehicles waiting to turn right or left at the intersection. Additionally, it must be ensured that the selected locations are close to the seniors facilities so that there are enough older drivers using the intersection. For the sake of meeting all those criteria, approximately thirty locations were checked in the Akron area, and only two intersections were finalized chosen for this research. The first T intersection is Fishcreek Road at Sowul Blvd, Stow, Ohio 44224, and the second site is located on East Ave at Community Road, Tallmadge, Ohio 44278, shown in Figure IV.3 and Figure IV.4.

Figure IV.3 - First Test Site (Fishcreek Road at Sowul Blvd, Stow, Ohio 44224)

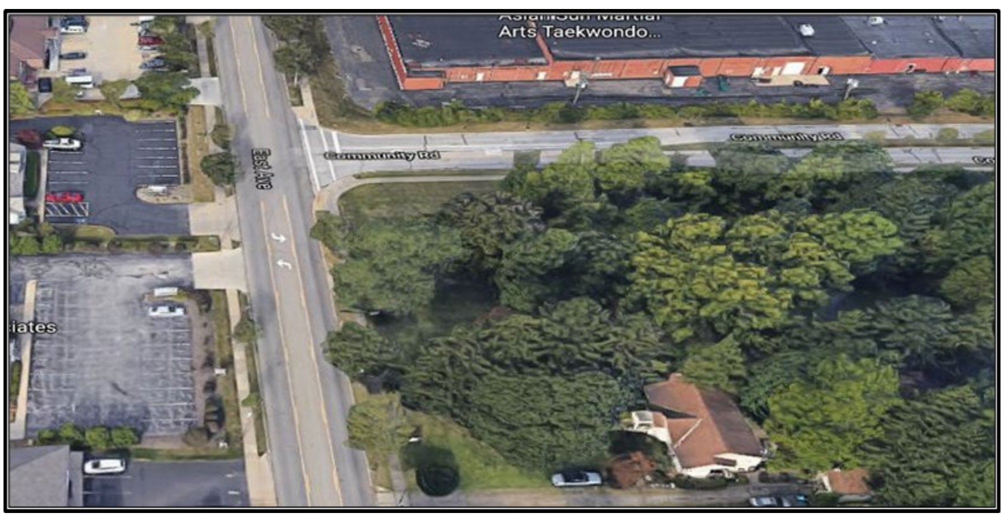

Figure IV.4 – East Avenue Location

1. Fishcreek Location

The characteristics of this location include:

- Two-lane major roads, two-lane minor roads, one lane in each direction, stop sign on minor road, as shown in Figure IV.5 and Figure IV.6.
- Two nearby senior facilities (the Landing of Stow and Altercare Western Reserve), many older drivers using this intersection, as shown in Figure IV.7.
- Level grade (assuming no effect on gap selection).
- Traffic signal located far enough (assuming no effect on gap selection).
- Sufficient volumes on minor and major roads.
- Non-platoon type of vehicle fleet on a major road.
- Sufficient sight distance based on the AASHTO standards (AASHTO, 2000).
- The average daily traffic (ADT) on the major road is 7,810 (website https://amatsplanning.org/), based on Akron Metropolitan Area Transportation Study, as shown in Figure IV.8.
- The major road speed is 35 mph, as shown in Figure IV.9.

Figure IV.5 Two-Lane Minor Road with Stop Sign Control

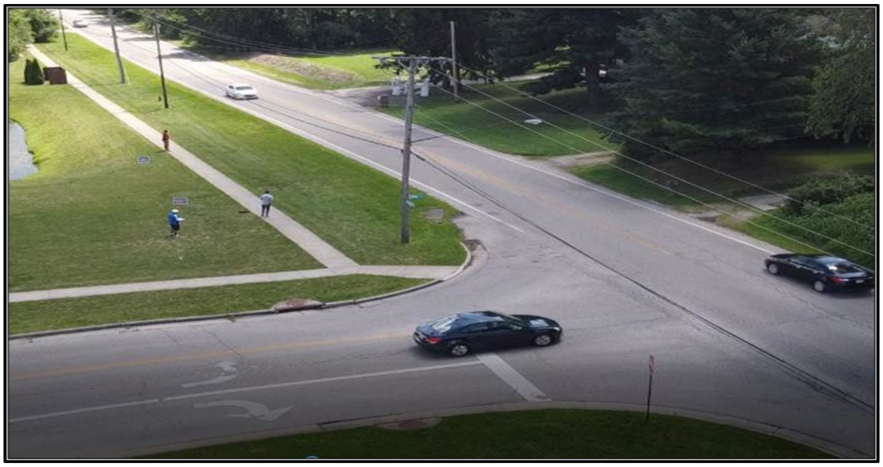

Figure IV.6 Two-Lane Major Road

Figure IV.7 - Fishcreak Location, General Layout

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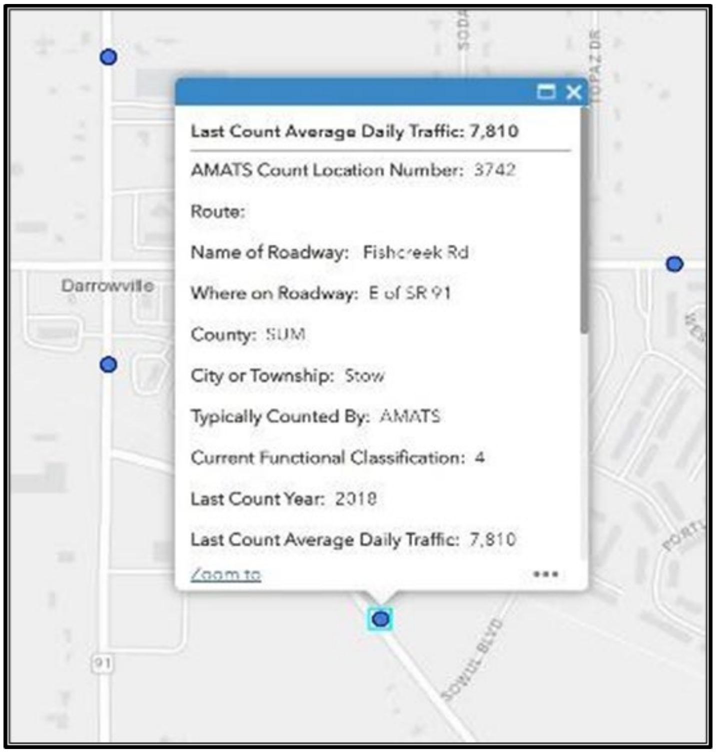

Figure IV.8 - Average Daily Traffic

Figure IV.9 - Major Road Speed Limit

2. East Avenue Location

The characteristics of this location are listed below:

- Two-lane major roads, two-lane minor roads, one lane in each direction, stop signs on minor roads, as shown in Figure IV.10 and Figure IV.11.
- Two nearby senior facilities (Faithful Servants Care Center, Northeast Family Health Care, Tallmadge Branch Library, and Danbury Senior Living Tallmadge), as shown in Figure IV.12. Many older drivers use this intersection.
- Level roadway surface.

- Traffic signal located far enough.
- Sufficient volumes on minor and major roads.
- Non-platoon type of vehicle fleet on major road.
- Sufficient sight distance based on the AASHTO standards (AASHTO, 2000).
- The major road speed limit is 35 mph, as shown in the figure (4.13).
- On major roads, the average daily traffic (ADT) is 8,350 (https://amatsplanning.org/) Akron Metropolitan Area Transportation Study, shown in Figure (4.14)

Figure IV.10 – Two-Lane Minor Road with Stop Sign

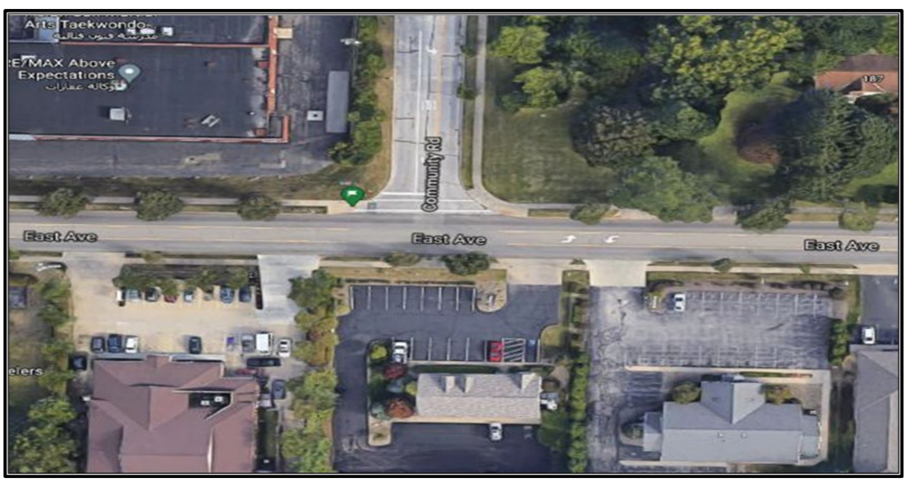

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Figure IV.11 – Two-Lane Major Road

Figure IV.12 – East Avenue Location, General Layout

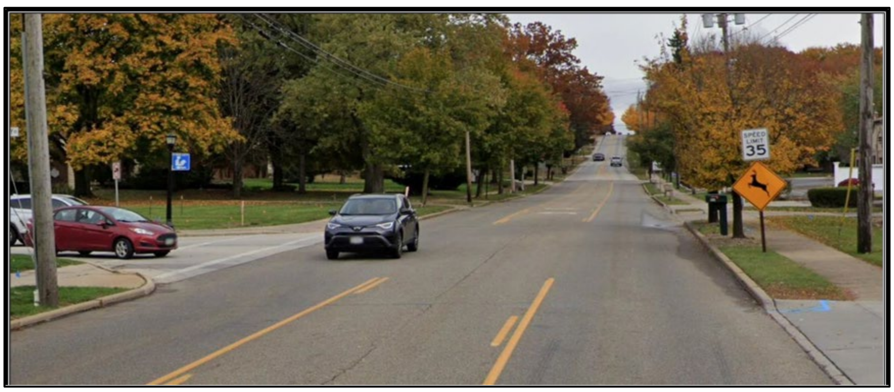

Figure IV.13 - Major Road Speed Limit

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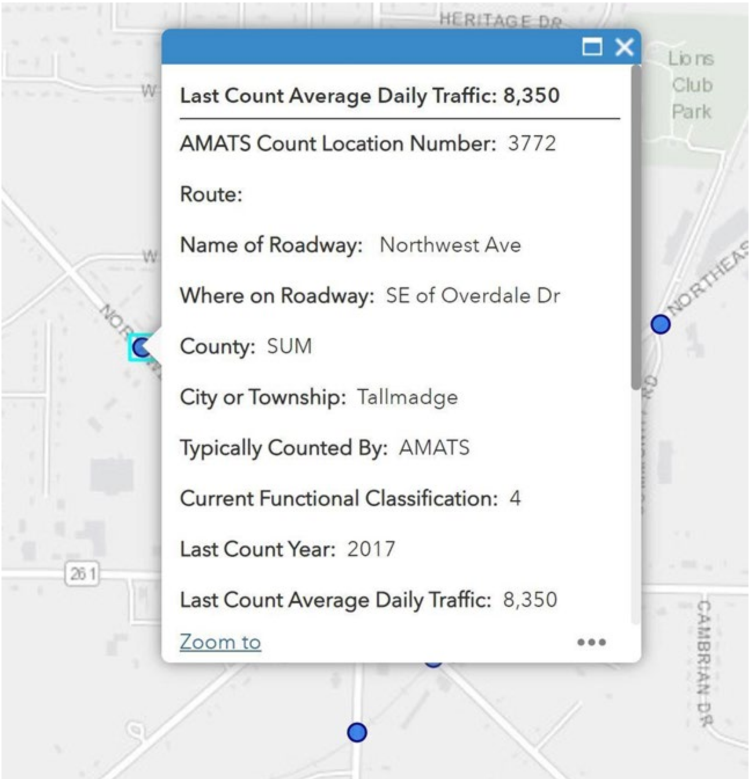

Figure IV.14 - Average Daily Traffic on Major Road

C. Gap Acceptance by Older Drivers

This study includes two test parts, each of them follows a different test procedure. The first part is to study old drivers' gap acceptance behavior at two intersections in support of developing the critical gap and accepted gaps. The rejected gap is also studied in this part, which is any gap that is not used by older drivers. In general, rejected gaps are smaller than the critical gap. The second part is to evaluate the effect of the new advisory system after installation and estimate its impact on safety and traffic operation.

1. Old drivers at Two Intersections

This focus in this part of study is on the age, selected time gaps (accepted and rejected gaps), gender, and vehicles turning right or left from the minor road, as shown in Table IV-1. To get identify older driver vs. other drivers, two personnel were trained to observe and judge the driver's age when a vehicle comes out of any of the senior living facilities. Moreover, if the age identification is vague, the data of that particular driver will be omitted from the study. Altogether, eight graduate students participated in the data collection process.

Table IV-1 Site Field Data Sheet

Minor Street Intersection									
Date: / / 2020				Majc Speed ( )VPH					
Time (From: To:)				Major Volume ( )VPH					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Old (**Y**es, **N**o, **D**on't)									
Male/Female (**M/F**)									
Left/ Right (**L/R**)									
Accept/Reject (**A/R**)									
Gap sec									

a. Tools and Devices

The vehicles were counted by using a combination of different tools and devices. These included drone (for video recording), radar (for detecting vehicle speed), stop-watch, red cones (for locating gaps), paint spray (for marking gaps in the ground), laser meter (Bosch) to measure distance, and counter (for counting the passing vehicles). The tools and devices are depicted in Figure IV.15 and Figure IV.16.

Before starting the test, the group prepares the site with the following steps:

- Assign interval distances on the ground by using the Bosh laser gun.
- The interval distances are located on the EBT direction and WBT in the major road, as shown in Figure IV.17 and Figure IV.18.
- Each interval distance has a red cone, as shown in Figure IV.19 and Figure IV.20. The used red cones are smaller size to avoid causing disturbance to the traffic flow.
- All marks and test materials are placed far enough on the roadside from traffic lanes.

Figure IV.15 - Test Tools

Figure IV.16 - Test Tools

Figure IV.17 – Site Preparation

Figure IV.18 - Gaps Measurement Preparation

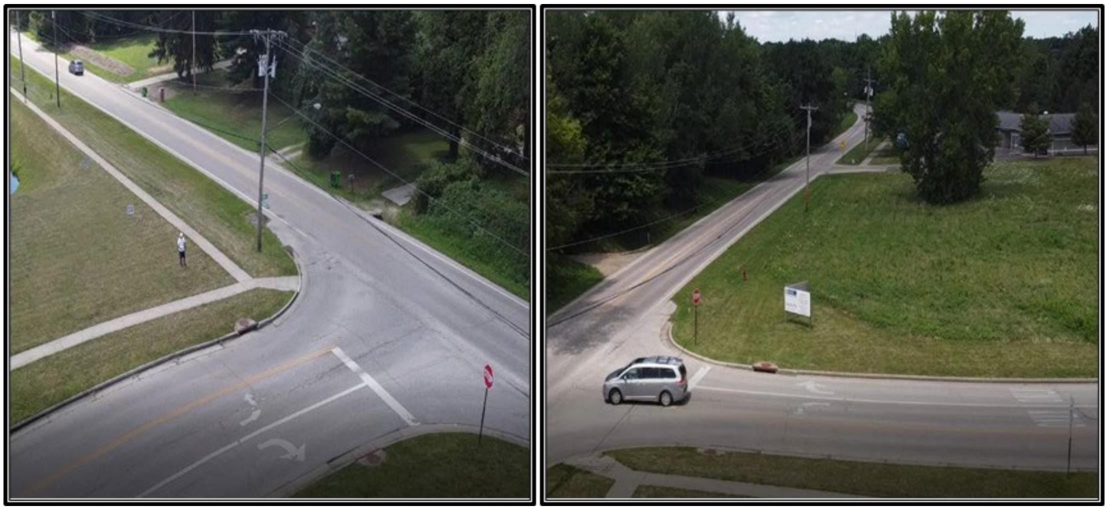

Figure IV.19 – Drone photos

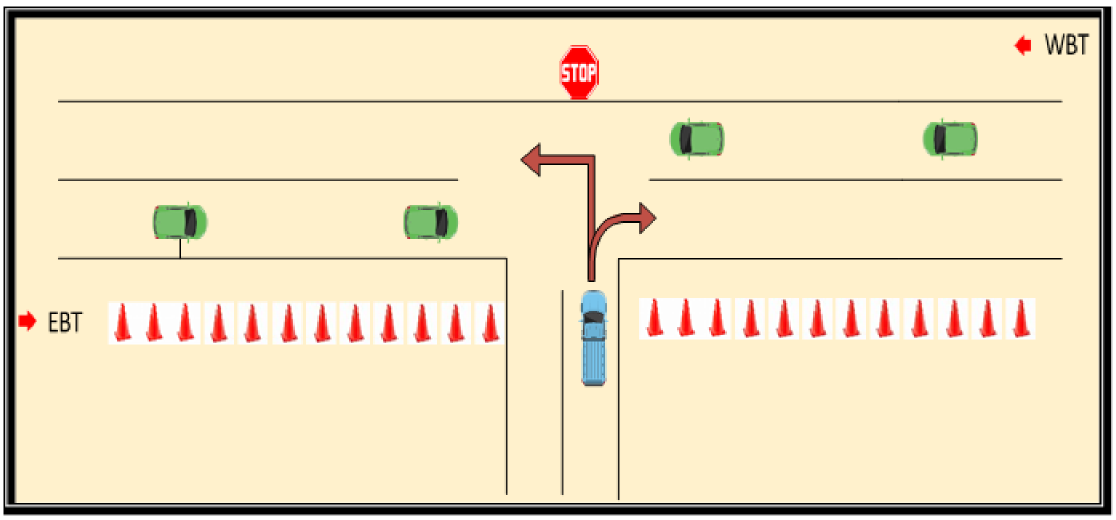

Figure IV.20 - Red Cones Location

b. Major road data acquisition

- Counting volume on the major road during the test.
- Identifying selected gaps in the traffic stream, measured in seconds.
- Controlling drone to record video during the test period.
- Measuring arriving speed of vehicles in EBT and WBT

c. Minor road data acquisition

- Counting volume on the minor road
- Identifying the driver's age and gender.
- Identifying the movement direction (right or left).
- Counting accepted and rejected usable gaps.
- Communicating with major road group to receive warning message.

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All research team members maintained live communication with each other through the WhatsApp App during the test.

2. Gap Acceptance Data Collection

The activity of collecting enough samples took approximately 70 hours in 60 days at both intersections. Gaps above 12 seconds were not considered in data collection because these gaps do not impose on older drivers to make choices under time pressure and similar findings were found in other studies (Kittelson and Vandehey, 1991). Moreover, all equipment including sensors, communication units, and markers were all located far away from the roadway near the intersection. The percentages of older drivers in both targeted intersections are shown in Figure IV.21 and Figure IV.22.

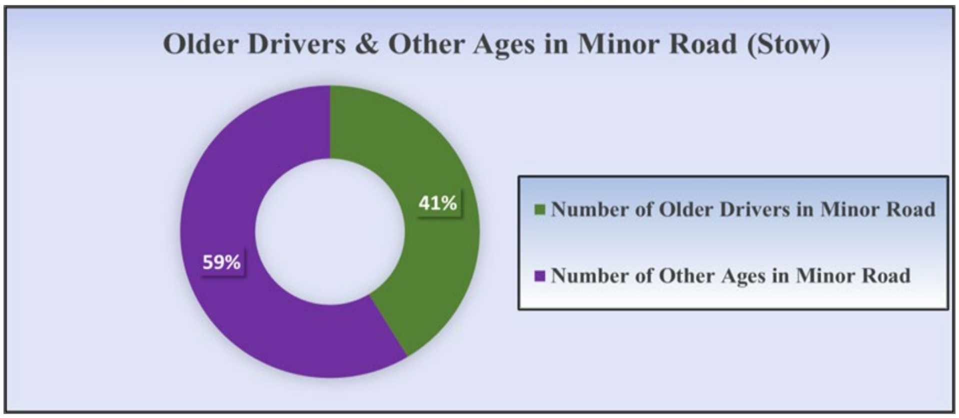


Figure IV.21 - Percentage of Older Drivers at Fishcreek Location

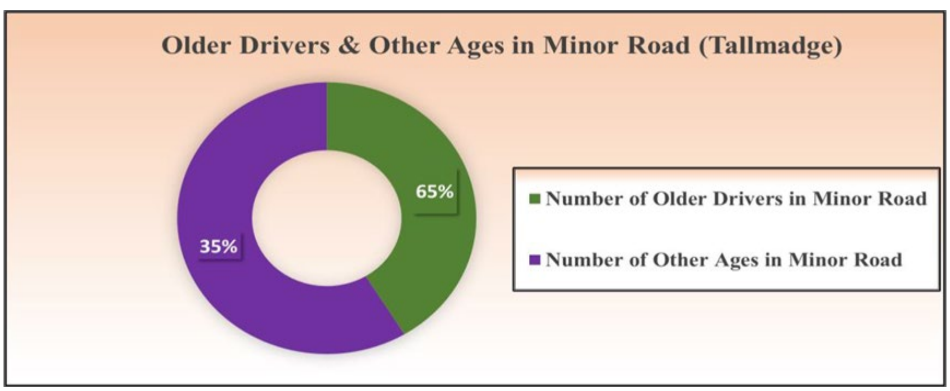


Figure IV.22 - Percentage of Older Drivers at East Avenue Location

It is important to note that drivers 65 or older are the main sample group in this study. Age estimation was conducted based on personal judgment and visual observation of the research team, together with the origin information (senior facility) of the vehicles. In most situations, there were no queues behind the vehicles on the minor road. In addition, those samples were not countered as valid points if the vehicles on the major road slowed down to turn (left or right) into the minor road.

3. Critical Gap Estimation

As discussed in the Literature Review section, different methods have been introduced by researchers/practitioners based on various theories. Hence, each of the methods has a distinguished mechanism for calculating the critical gap. Among them, however, Raff and Ashworth method seems to be more widely used (Ashworth, 1970), thus, it was chosen for critical gap estimation in this research.

Raff's method defines the critical gaps as the size of the gap for which the number of gaps longer than it equals the number of gaps shorter than it. This definition sets an easy way for calculating the critical gap, which is located at the intercepting point of the cumulative acceptance probability curve and the cumulative rejection probability curve (Mohan and Chandra, 2016). Mathematically, it can be written as:

$$1 - Fr(t) = Fa(t)$$

Where the value of t is the critical gap, and Fa and Fr are probability distribution functions of rejected and accepted gaps, respectively.

The accumulative probability curves based on field data show that the critical gap at the Fishcreek location was 7.40, as shown in Figure IV.23, and 6.5 seconds at the East Avenue location, as shown in Figure IV.24.

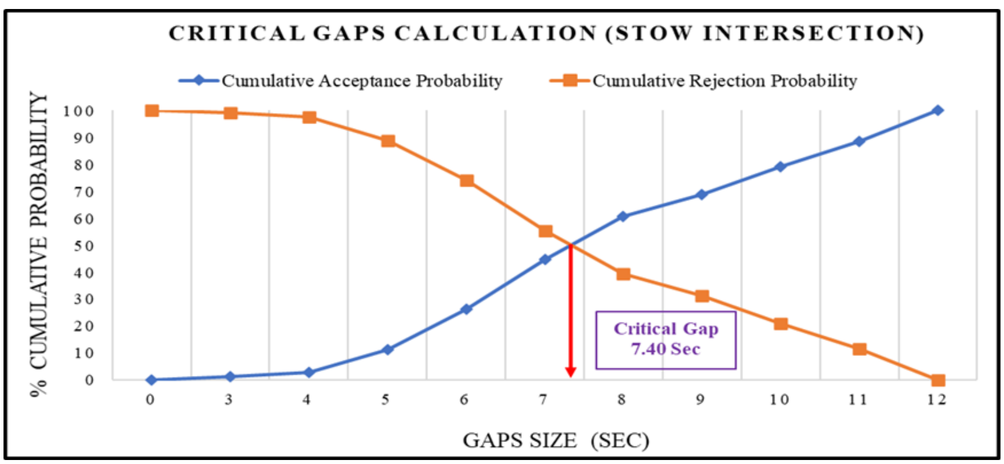


Figure IV.23 - Accumulative Probability Curves at Fishcreek Location

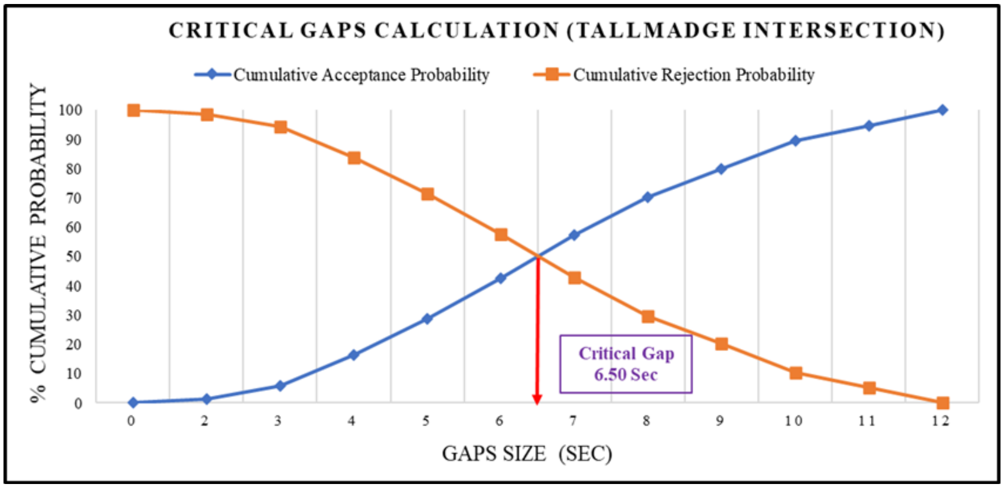


Figure IV.24 - Accumulative Probability Curves at East Avenue Location

The value of the critical gap values obtained from both test locations were used as the basis of determining a safe vs. unsafe gap in the proposed safety advisory system during the field test Those values were also used in the simulation study to evaluate the impact on traffic operation due to using the advisory system.

D. Field Test

1. Controlled Situation

In the controlled situation, vehicles on the major road can communicate with each other and with the central system, simulating a connected vehicle environment. The field test in this situation is supported by the following three components.

a. Advisory System

The system hardware includes four XBee Zigbee modules, four XBee Explorer USB, two GPS, two laptops, two USB type A to mini type B plugs, USB cables, and a Data Acquisition Unit.

The XBee Explorer USB is plugged into Xbee, after which it is attached to a mini USB cable. XBee Explorer has a direct access to the programming and serial pins on the XBee module through this connection, as shown in Figure IV.25. XBee Zigbee modules are used for wireless communication without the need for the Internet. Also, XBee Zigbee modules are designed to work in multiple frequencies and wireless protocols, which enable them to communicate efficiently. A sample of datasheet for Xbee Zigbee is shown in Figure IV.26.

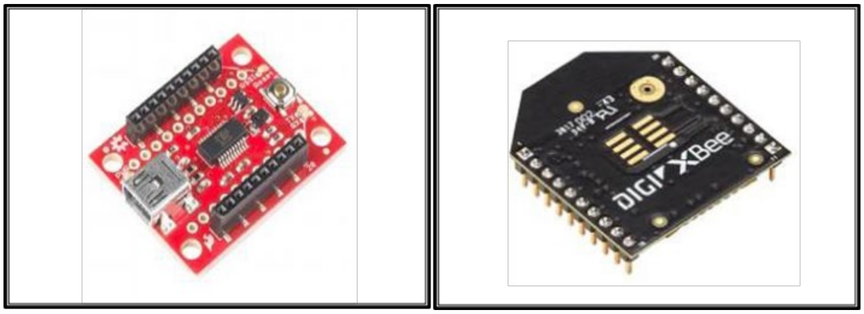


Figure IV.25 - XBee Zigbee Modules

SPECIFICATIONS	Digi XBee® 3 Zigbee 3.0	Digi XBee® 3 PRO Zigbee 3.0
PERFORMANCE		
TRANSCEIVER CHIPSET	Silicon Labs EFR32MG SoC	
DATA RATE	RF 250 Kbps, serial up to 1 Mbps	
INDOOR/URBAN RANGE*	Up to 60 m (200 ft)	Up to 90 m (300 ft)
OUTDOOR/RF LINE-OF-SIGHT RANGE*	Up to 1200 m (4000 ft)	Up to 3200 m (2 miles)
TRANSMIT POWER	+8 dBm	+19 dBm
RECEIVER SENSITIVITY (1% PER)	-103 dBm Normal Mode	
FEATURES		
SERIAL DATA INTERFACE	UART, SPI, I²C	
CONFIGURATION METHOD	API or AT commands, local or over-the-air (OTA)	
FREQUENCY BAND	ISM 2.4 GHz	
FORM FACTOR	Micro, through-hole, surface mount	
INTERFERENCE IMMUNITY	DSSS (Direct Sequence Spread Spectrum)	
ADC INPUTS	(4) 10-bit ADC inputs	
DIGITAL I/O	15	
ANTENNA OPTIONS	Through-hole: PCB Antenna, U.FL Connector, RPSMA Connector SMT: RF Pad, PCB Antenna, or U.FL Connector Micro: U.FL Antenna, RF Pad, Chip Antenna	
OPERATING TEMPERATURE	-40° C to 85° C (-40° F to 185° F)	
DIMENSIONS (L X W X H)	Through-hole: 2.438 x 2.761 cm (0.960 x 1.087 in) SMT: 2.199 x 3.4 x 0.305 cm (0.866 x 1.33 x 0.120 in) Micro: 13 x 19 x 2 mm (0.533 x 0.76 x 0.087 in)	
PROGRAMMABILITY		
MEMORY	1 MB / 128 KB RAM (32KB are available for MicroPython)	
NETWORKING AND SECURITY		
PROTOCOL	Zigbee® 3.0	
ENCRYPTION	128/256 bit AES	
RELIABLE PACKET DELIVERY	Retries/acknowledgements	
IDS	PAN ID and addresses, cluster IDs and endpoints (optional)	
CHANNELS	16 channels	
POWER REQUIREMENTS		
SUPPLY VOLTAGE	2.1 to 3.6 V	
TRANSMIT CURRENT	40 mA @ 8 dBm	135 mA @ 19 dBm
RECEIVE CURRENT	17 mA	

Figure IV.26 - XBee Zigbee Module Datasheet

The GPS is a highly sensitive and low-power consumption device and it is USB magnet mounted. It is Windows 10 compatible, powered by a SiRF Star IV GPS chipset to locate the position and measure speed of major road vehicles approaching the intersection, as shown in Figure IV.27.

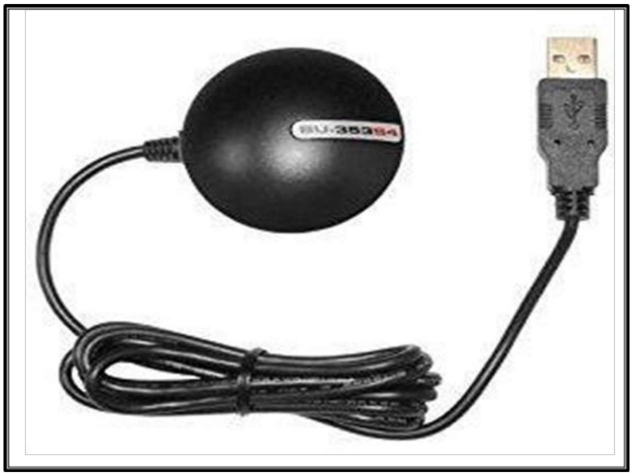


Figure IV.27 – GPS

A laptop computer supporting Python programming is an essential component for the advisory system, as shown in Figure IV.28.

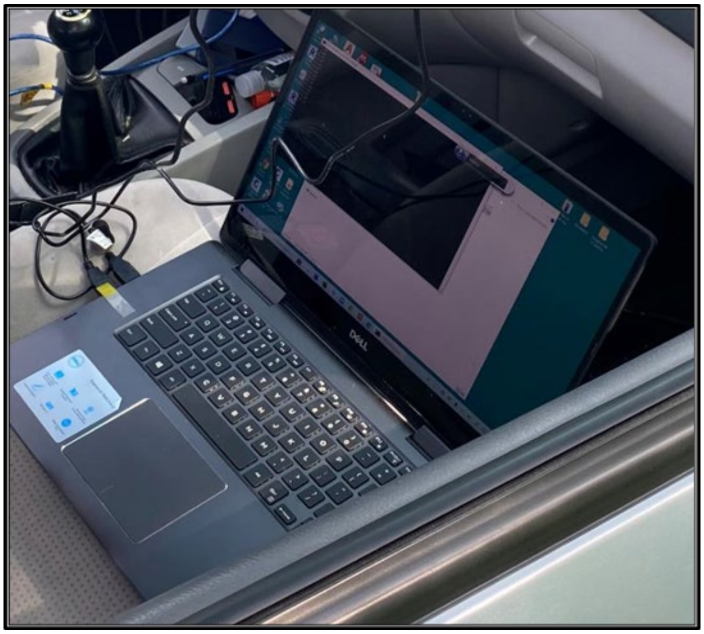


Figure IV.28 - Laptop Computer with the Python Software

The USB type A plug to mini type B plugs connects the Xbee Zigbee module to the laptop, as shown in Figure IV.29.

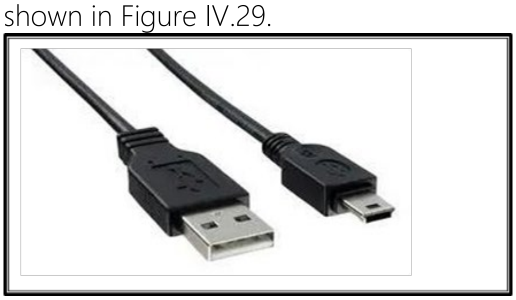


Figure IV.29 - USB Type A to Mini Type B Plug

The USB type A to type B plug connects the Data Acquisition Unit to the power charger, as shown in Figure IV.30.

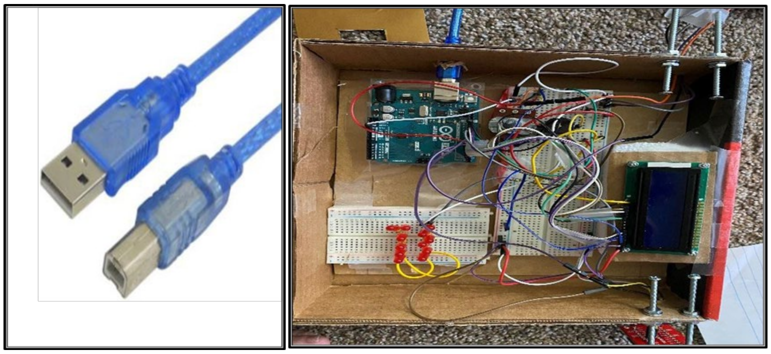


Figure IV.30 - USB Type A to Type B Plug

The Data Acquisition Unit is developed to gather data that are further processed to reach the decision if or not to issue a warning message, as shown in Figure IV.31.

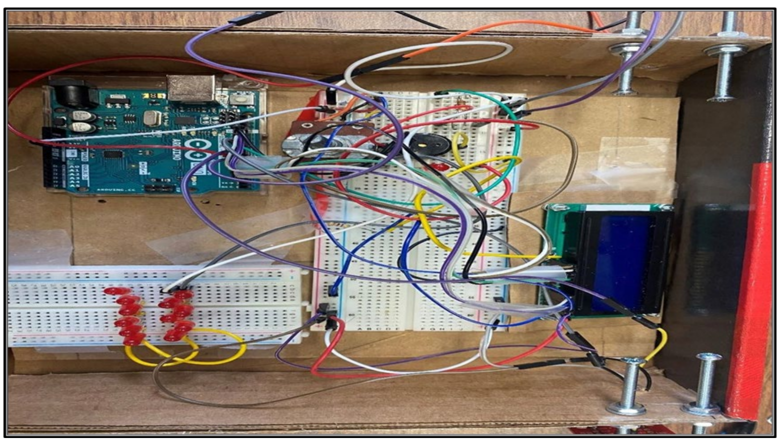


Figure IV.31 - Data Acquisition Unit

b. System Installation

Installation of the advisory system involves two steps. The first step includes the parts on the major road whereas the second step handles those on minor road and inside the older driver vehicles, as shown in Figure IV.32 and Figure IV.33.

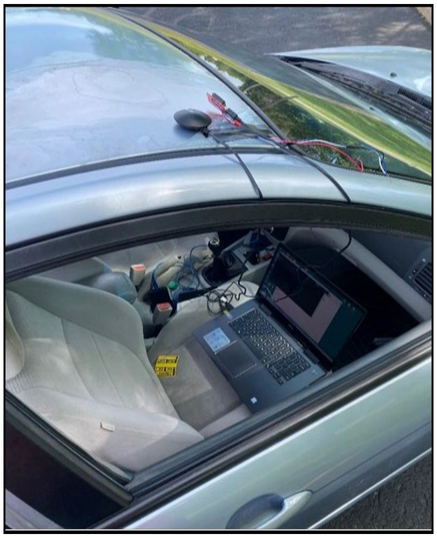


Figure IV.32 - XBee and GPS and Laptop in Major Road Vehicles

Figure IV.33 - Data Acquisition Unit in the Older Driver Vehicle

c. Test Procedure

When a vehicle on the minor road is pulling up to the intersection, as shown in Figure IV.34, it communicates with the central system about the presence and status of the vehicles on the major road. If there are connected vehicles on the major road in the data communication range, the GPS in those vehicles receive requests and send out the data to the laptop, which include the speed and distance of the vehicles towards the intersection. The Python code gets the information and calculates the actual gap, which is then sent to the minor road vehicle via Xbee Zigbee, as shown in Figure IV.35. The Data Acquisition Unit at minor road vehicle receives the information and checks the gaps against the critical gap (obtained earlier from the local data). If the gap is smaller than the critical gap, then the Data Acquisition Unit will present three types of warnings: beeping, red flashing, and message at LCD, as shown in Figure IV.36.

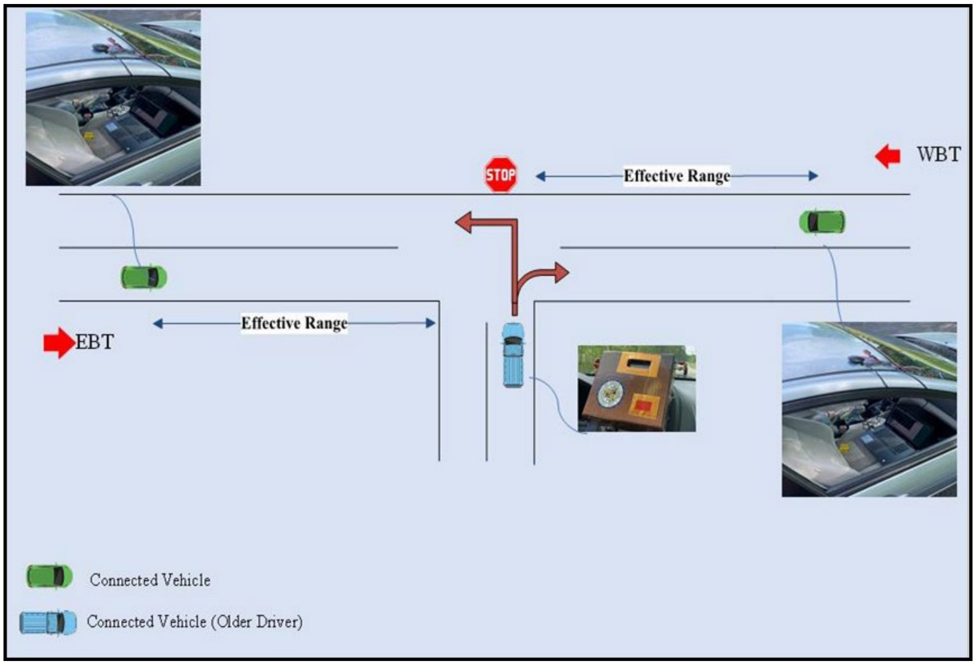
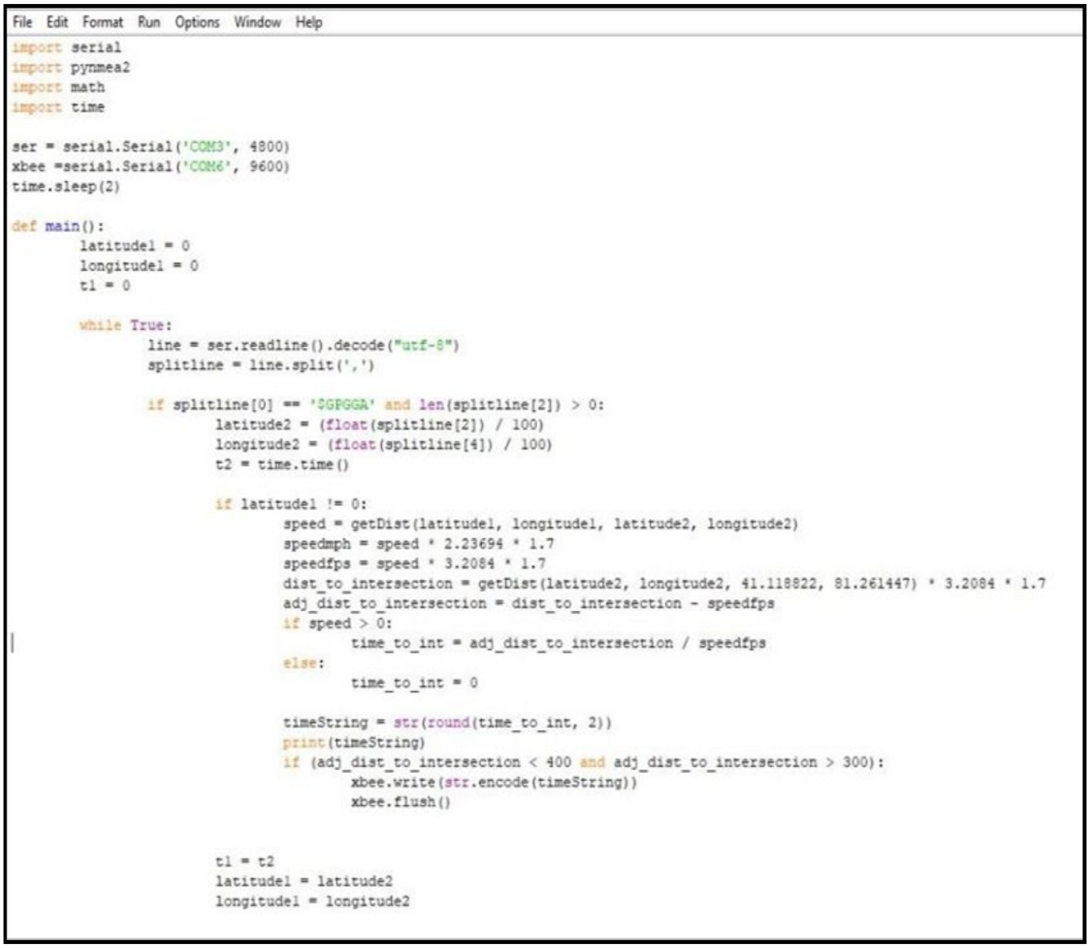


Figure IV.34 - Controlled Situation Test Procedure

The warnings will continue to work until the vehicle on the major road passes the intersection. However, if the oncoming gap is larger than the critical gap, then no action is taken and it is up to the older driver to take the gap or let it pass.



```
import serial
import pynmea2
import math
import time

ser = serial.Serial('COM3', 4800)
xbee =serial.Serial('COM6', 9600)
time.sleep(2)

def main():
        latitude1 = 0
        longitude1 = 0
        t1 = 0

        while True:
                line = ser.readline().decode("utf-8")
                splitline = line.split(',')

                if splitline[0] == '$GPGGA' and len(splitline[2]) > 0:
                        latitude2 = (float(splitline[2]) / 100)
                        longitude2 = (float(splitline[4]) / 100)
                        t2 = time.time()

                        if latitude1 != 0:
                                speed = getDist(latitude1, longitude1, latitude2, longitude2)
                                speedmph = speed * 2.23694 * 1.7
                                speedfps = speed * 3.2084 * 1.7
                                dist_to_intersection = getDist(latitude2, longitude2, 41.118822, 81.261447) * 3.2084 * 1.7
                                adj_dist_to_intersection = dist_to_intersection - speedfps
                                if speed > 0:
                                        time_to_int = adj_dist_to_intersection / speedfps
                                else:
                                        time_to_int = 0

                                timeString = str(round(time_to_int, 2))
                                print(timeString)
                                if (adj_dist_to_intersection < 400 and adj_dist_to_intersection > 300):
                                        xbee.write(str.encode(timeString))
                                        xbee.flush()


                        t1 = t2
                        latitude1 = latitude2
                        longitude1 = longitude2
```

Figure IV.35 - Python Code

Figure IV.36 - Types of Warnings in the Data Acquisition Unit

2. Uncontrolled Situation

In an uncontrolled situation, the vehicles on the major road cannot communicate with each other nor with the central system. In this situation, only minor road vehicles can communicate with the central system. Therefore, installing external sensors is required on the major road to detect the speed and distance data for major road vehicles. The following three components are essential to the field experiment in this situation.

a. Advisory System

The hardware for the advisory system comprises of four Smraza Ultrasonic Module HC-SR04, four XBee Zigbee modules, four XBee Explorer USB, three USB type A to type B plugs, two Arduino Uno SMD R3, and a Data Acquisition Unit. A brief description for each the above is given below.

Smraza Ultrasonic Module HC-SR04 sends eight 40 kHz signals automatically and detects whether there is a pulse signal back. The detection range of the module is 0.78 to 196 inches (2cm~500cm); High precision is 0.12 inch (0.3 cm), the effectual angle is less than 15°. The power supply required is 5V DC , as shown in Figure IV.37.

Figure IV.37 - Smraza Ultrasonic Module HC-SR04

The XBee Explorer USB is plugged into Xbee and then soldered with the power, send, receive and ground wires, as shown in Figure IV.38. Through this connection, the XBee Explorer has direct access to the programming and serial pins on the XBee module. The XBee Zigbee modules are used for wireless communication without the internet.

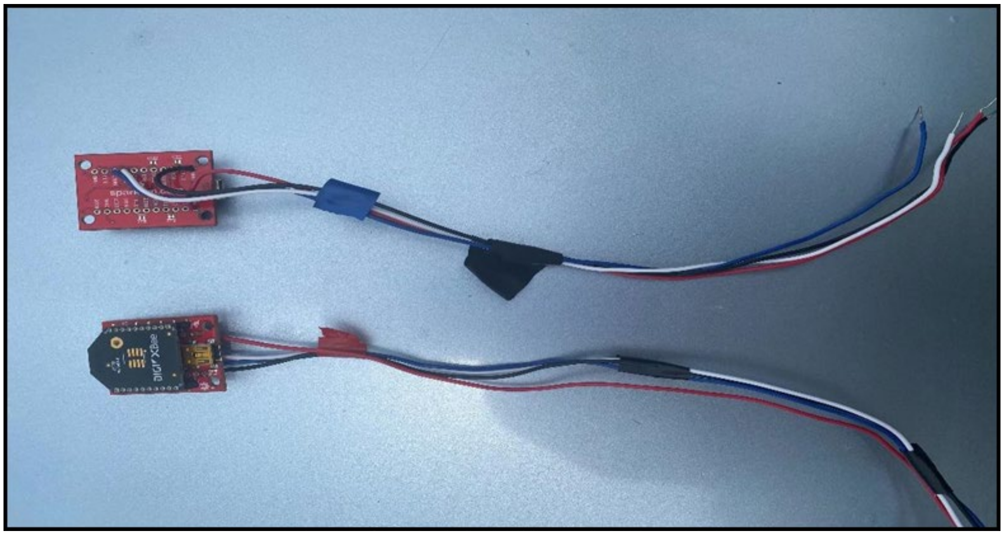


Figure IV.38 - XBee Explorer USB Plugged into Xbee and Soldered to Power Wire

The USB type A to type B plug is used to connect the Data Acquisition Unit to the power charger, as shown in Figure IV.39.

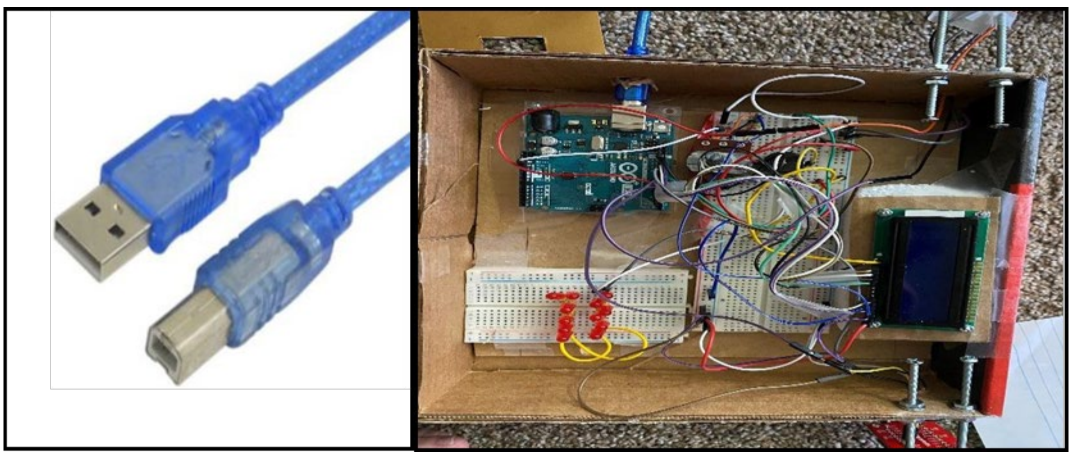


Figure IV.39 - USB Cable Type A Plug to Type B Plug

The Arduino Uno SMD R3 is a microcontroller board with 14 digital input and output pins, a USB connection, and a reset button, as shown in Figure IV.40. The datasheet for used Arduino is shown in Figure IV.41.

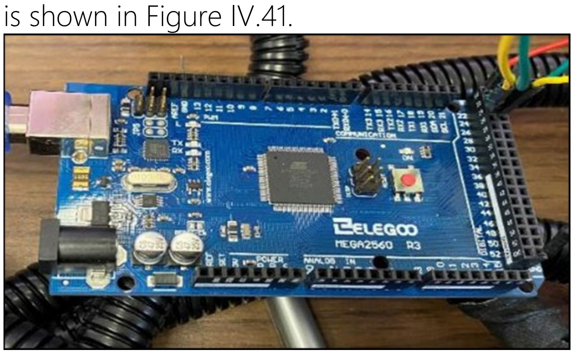


Figure IV.40 - Arduino Uno SMD R3

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	614 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure IV.41 - Arduino Datasheet

The Data Acquisition Unit is a critical component used for the collection of data, as shown in Figure IV.42.

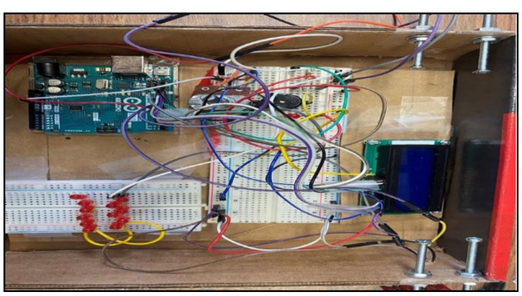


Figure IV.42 - Data Acquisition Unit

b. System Installation

There are two steps. The first involves the system hardware along the major road, and the second includes those on the minor road and inside the older driver vehicles. Those two steps are shown in Figure IV.43, Figure IV.44, Figure IV.45, and Figure IV.46.

Figure IV.43 - Installing Smraza Ultrasonic sensor along Major Road

Figure IV.44 - Connecting XBee Zigbee to Arduino Uno SMD R3

Figure IV.45 - Connecting XBee Zigbee to Arduino Uno SMD R3

Figure IV.46 - Data Acquisition Unit in the Older Driver Vehicle

c. Test Procedures

In the uncontrolled situation, the vehicle on the minor road starts requesting data collected by the sensors along the major road (shown in Figure IV.47). The sensors on a major road send the data to Arduino, which receives and sends the results to the minor road vehicle via XbeeZigbee. The Data Acquisition Unit in the minor road vehicle gets the information via Xbee Zigbee and checks the gaps against the critical gap. Following the same rule, if the gap is smaller than the critical gap, the Data Acquisition Unit will present three types of warnings: beeping, red flashing, and message via the LCD, as shown in Figure IV.48. The three types of warnings will continue to work until the vehicle on the major road passes through the intersection. On the other hand, if the gap is larger than the safe gap, then no action is taken.

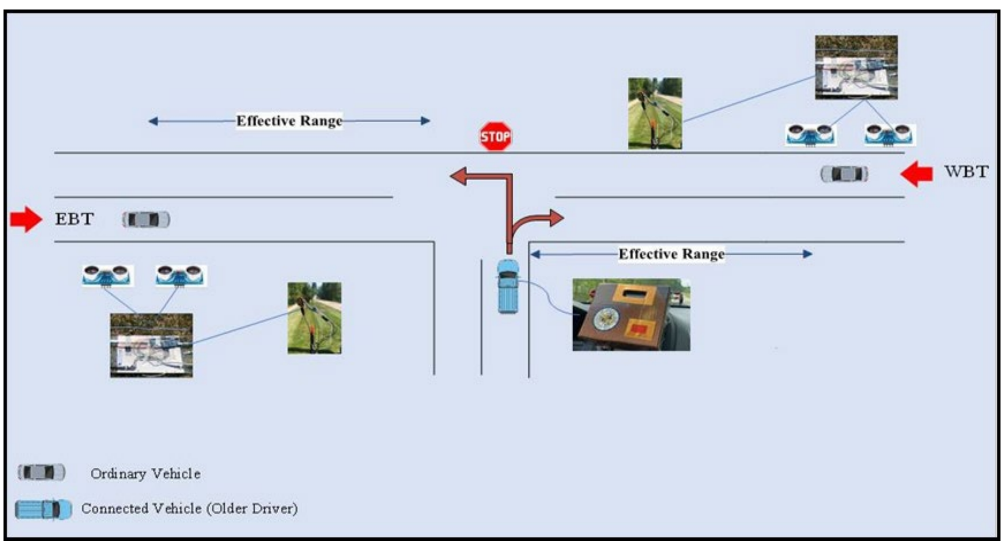


Figure IV.47 - Uncontrolled Situation Test Procedure

Figure IV.48 - Data Acquisition Unit presenting Three Types of Warnings

V. SIMULATION OF TRAFFIC IMPACT

A. Background

The PTV VISSIM is one of the leading microscopic simulation programs in traffic simulation and analysis today. The software has several features, including traffic light engineering, vehicle queue length analysis, traffic flow modeling, script-based modeling, and pedestrian simulation (Ramadhan, Joelianto, and Sutarto, 2019). It is an effective, flexible, and advanced software due to the following reasons:

1. Providing microscopic level simulation for highly complex vehicle interactions.
2. Providing simulation of CAV and Mobility as a Service (MaaS) applications, which are recent forms of mobility.
3. Entailing the capability of the supply, demand, and behavior with greater detail.
4. Ensuring seamless integration with the world's leading traffic planning tool namely PTV.

The COM interface of VISSIM is commonly used in simulation. It provides users with a standardized application programming interface for developing a particular user application and VISSIM in the background. This interface provides a completely defined hierarchical model where the functions and their associated parameters of the simulator can be changed through programming. Any programming language that supports COM objects can be used, such as C++, Java, Python, Visual Basic, etc.

Therefore, this research utilizes VISSIM 9 (PTV VISSIM, 2016) to build the module and run the simulation under different controlling parameters along with different traffic flow conditions. The Python programming language has been used to develop the COM program.

B. Building Simulation Model

This simulation looks into the efficiency and safety of applying the proposed advisory system in contrast with do-nothing.

One of the important parameters in this research is the critical gap. Staplin et al. (2001) have recommended having a minimum gap of 8.0s plus 0.5s for every additional lane crossed by the driver to address older drivers' slower decision times.

In addition, the Federal Highway Administration's recommendation in Publication No. FHWA-RD-01-051 U.S. suggests that, with the presence of safety gap selection for older drivers, a minimum of eight seconds should be used as the critical gap. On the other hand, the critical gap based on Highway Capacity Manual 2020 (Exhibit 19-10) is 6.5 seconds as an average.

Realizing the importance of local influencing factors to the critical gap, this research endeavored to find the critical gap based on the older drivers' gap selection data at the two test locations in

Summit County, Ohio. Field data were used to not only develop the gap related parameters, but also understand vehicle arrival characteristics and identify drivers' age group and gender.

The simulation has also studied the impeded speed. The impeded speed represents the forced reduction of speed by the major road vehicles due to the roadway entrance of old driver vehicles. Since tracking impeded speeds is not directly unavailable in VISSIM GUI, customized algorithms via Python with COM interface have been written by the research team to help with this calculation. The methodological process for this work is shown in Figure V.1.

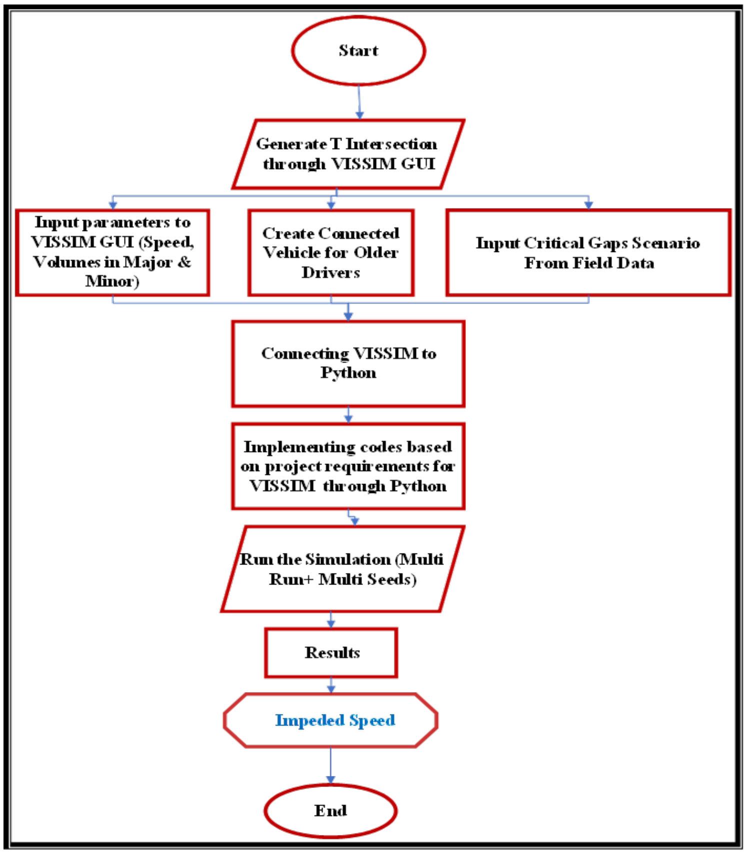


Figure V.1 - Methodological process for Calculating Impeded Speed

The first step involves creating a traffic network according to the test site geometry, as shown in Figure V.2. The traffic network is composed of a two-lane highway as the major road, and an intersecting minor road for vehicles to enter or exit from the major road.

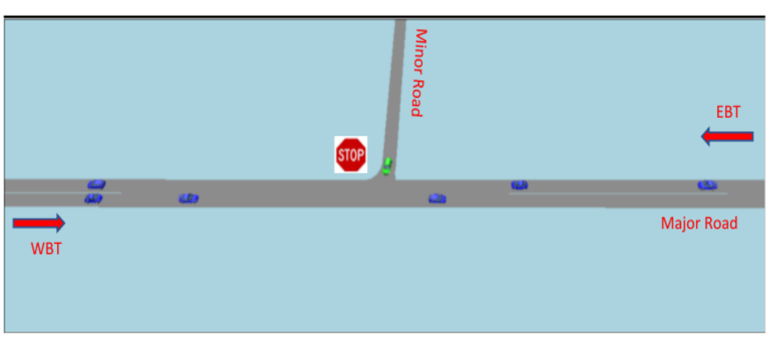


Figure V.2 - Traffic Network

The next step is to set up an area for conducting simulation evaluation around the intersection, as shown in Figure V.3.

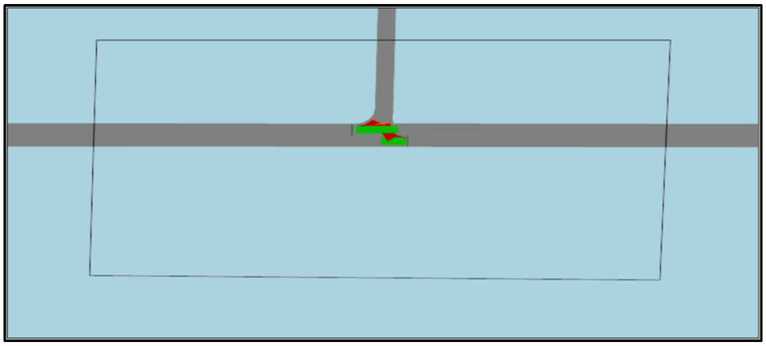


Figure V.3 - Test Area

Although VISSIM is capable of providing basic measurements of effectiveness (MOEs), a special Python code has to be written and executed through the COM interface for impeded speeds assessment. A sample of the Python code is shown in Figure V.4.

File Edit Format Run Options Window Help

```python
def init():

    global minSpeed_eb
    global minSpeed_wb
    minSpeed_eb = 99999
    minSpeed_wb = 99999

    global minArray_eb
    global minArray_wb
    minArray_eb = [None] * 100000
    minArray_wb = [None] * 100000

    global fromMinor
    fromMinor = []

    global prevMinor
    prevMinor = [0]


    return

def main():

    global minSpeed_eb
    global minSpeed_wb
    global fromMinor
    global prevMinor

    minor_veh = Vissim.Net.Links.ItemByKey(1).Vehs.GetAll()      # array of vehicles coming from minor street
    wb_veh = Vissim.Net.Links.ItemByKey(12).Vehs.GetAll()        # array of vehicles on WB major street
    eb_veh = Vissim.Net.Links.ItemByKey(11).Vehs.GetAll()        # array of vehicles on EB major street

    for v in minor_veh:
        doAppend = True
        for i in fromMinor:
            if v.AttValue('No') == i:
                doAppend = False

        if doAppend:
            fromMinor.append(v.AttValue('No'))

    for no in fromMinor:
        doDelete = True
        for v in Vissim.Net.Vehicles.GetAll():
            if v.AttValue('No') == no:
                doDelete = False
        if doDelete:
            fromMinor.remove(no)


    # Check for min speed of west bound vehicles
    for v in wb_veh:

        turnVeh = False
        for mVeh in fromMinor:
            if mVeh == v.AttValue('No'):
                turnVeh = True

        if turnVeh == False:
            if v.AttValue('Speed') < minSpeed_wb:
                minSpeed_wb = v.AttValue('Speed')

            if v.AttValue('Speed') < minArray_wb[v.AttValue('No')] or minArray_wb[v.AttValue('No')] == None:
                minArray_wb[v.AttValue('No')] = v.AttValue('Speed')
```

Figure V.4 - Part of Python Code for Calculating Impeded Speed

C. Number of Seeds, Period, and Number of Simulations

The simulation work was performed for one hour (3600 sec) in each run. The minimal number of simulation runs in each case is 5 with different random seeds, and the outputs from all 5 runs are averaged to reach the final results, as exemplified Figure V.5 and Figure V.6.

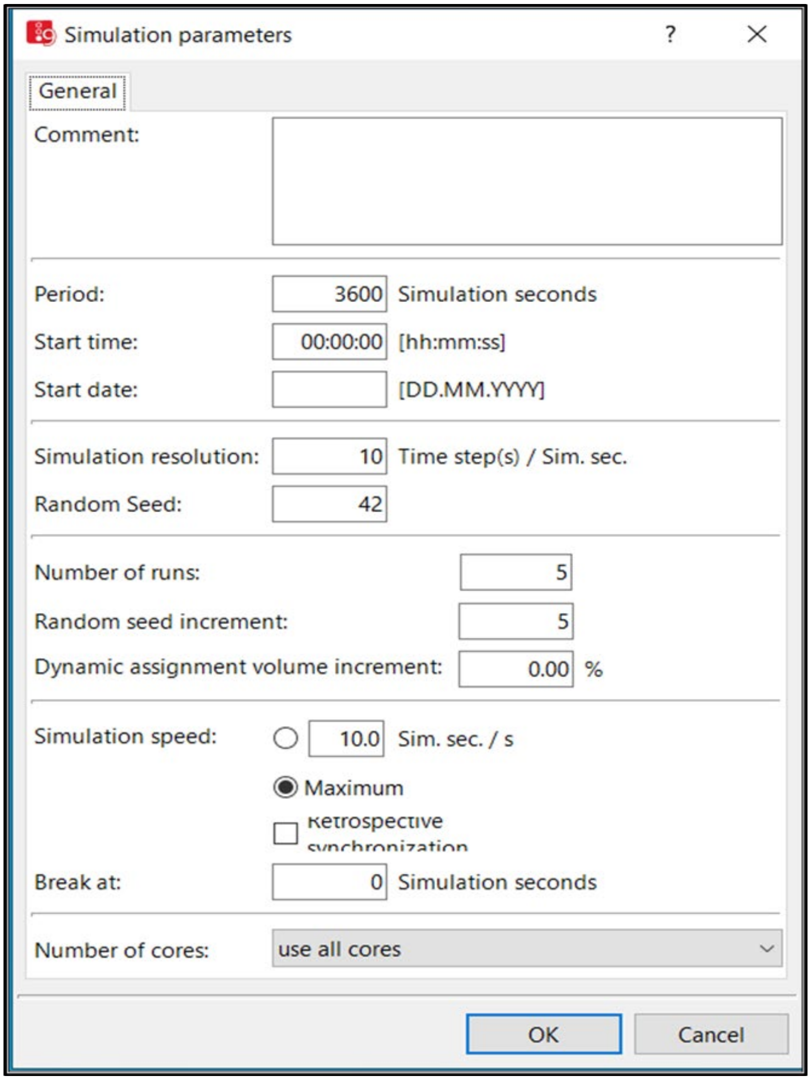
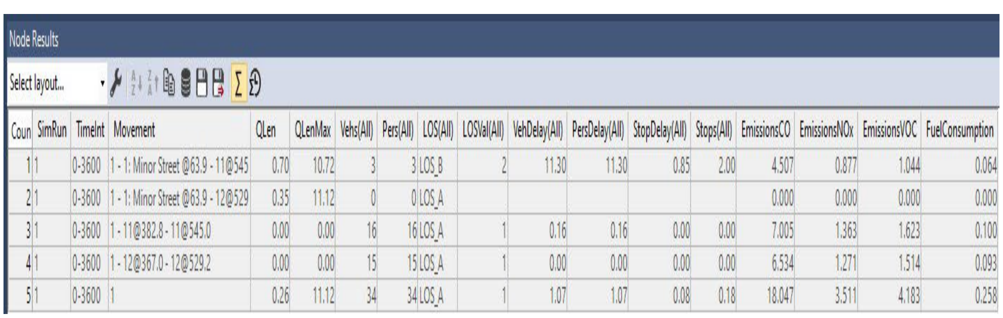
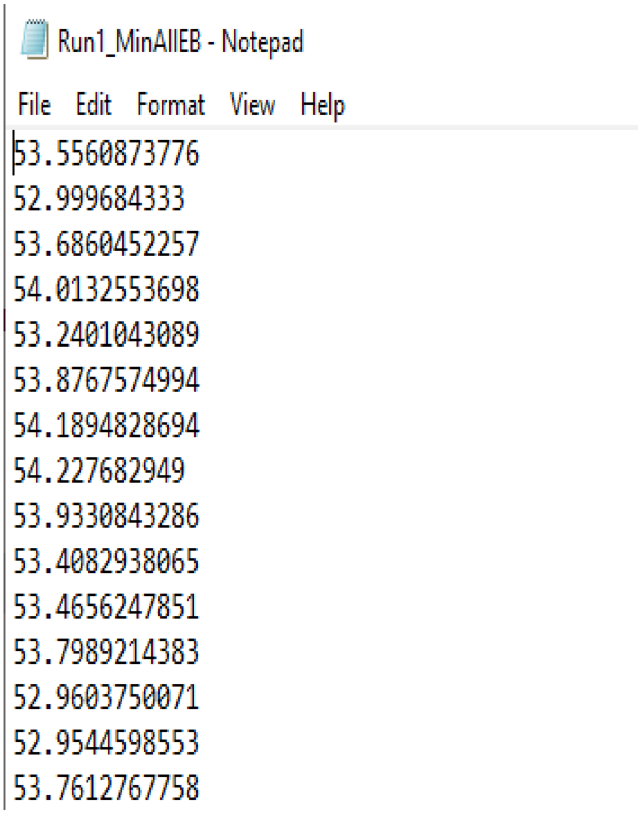


Figure V.5 - Number of Seeds, Period, and Number of Simulation


Node Results

Coun	SimRun	TimeInt	Movement	QLen	QLenMax	Vehs(All)	Pers(All)	LOS(All)	LOSVal(All)	VehDelay(All)	PersDelay(All)	StopDelay(All)	Stops(All)	EmissionsCO	EmissionsNOx	EmissionsVOC	FuelConsumption
1	1	0-3600	1 - 1: Minor Street @63.9 - 11@545	0.70	10.72	3	3	LOS_B	2	11.30	11.30	0.85	2.00	4.507	0.877	1.044	0.064
2	1	0-3600	1 - 1: Minor Street @63.9 - 12@529	0.35	11.12	0	0	LOS_A						0.000	0.000	0.000	0.000
3	1	0-3600	1 - 11@382.8 - 11@545.0	0.00	0.00	16	16	LOS_A	1	0.16	0.16	0.00	0.00	7.005	1.363	1.623	0.100
4	1	0-3600	1 - 12@367.0 - 12@529.2	0.00	0.00	15	15	LOS_A	1	0.00	0.00	0.00	0.00	6.534	1.271	1.514	0.093
5	1	0-3600	1	0.26	11.12	34	34	LOS_A	1	1.07	1.07	0.08	0.18	18.047	3.511	4.183	0.258



Run1_MinAllEB - Notepad

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53.5560873776
52.999684333
53.6860452257
54.0132553698
53.2401043089
53.8767574994
54.1894828694
54.227682949
53.9330843286
53.4082938065
53.4656247851
53.7989214383
52.9603750071
52.9544598553
53.7612767758

Figure V.6 – Sample Simulation Result

D. Plan of Simulation

The flow chart shown in Figure V.7 illustrates the plan of simulation and the model input:

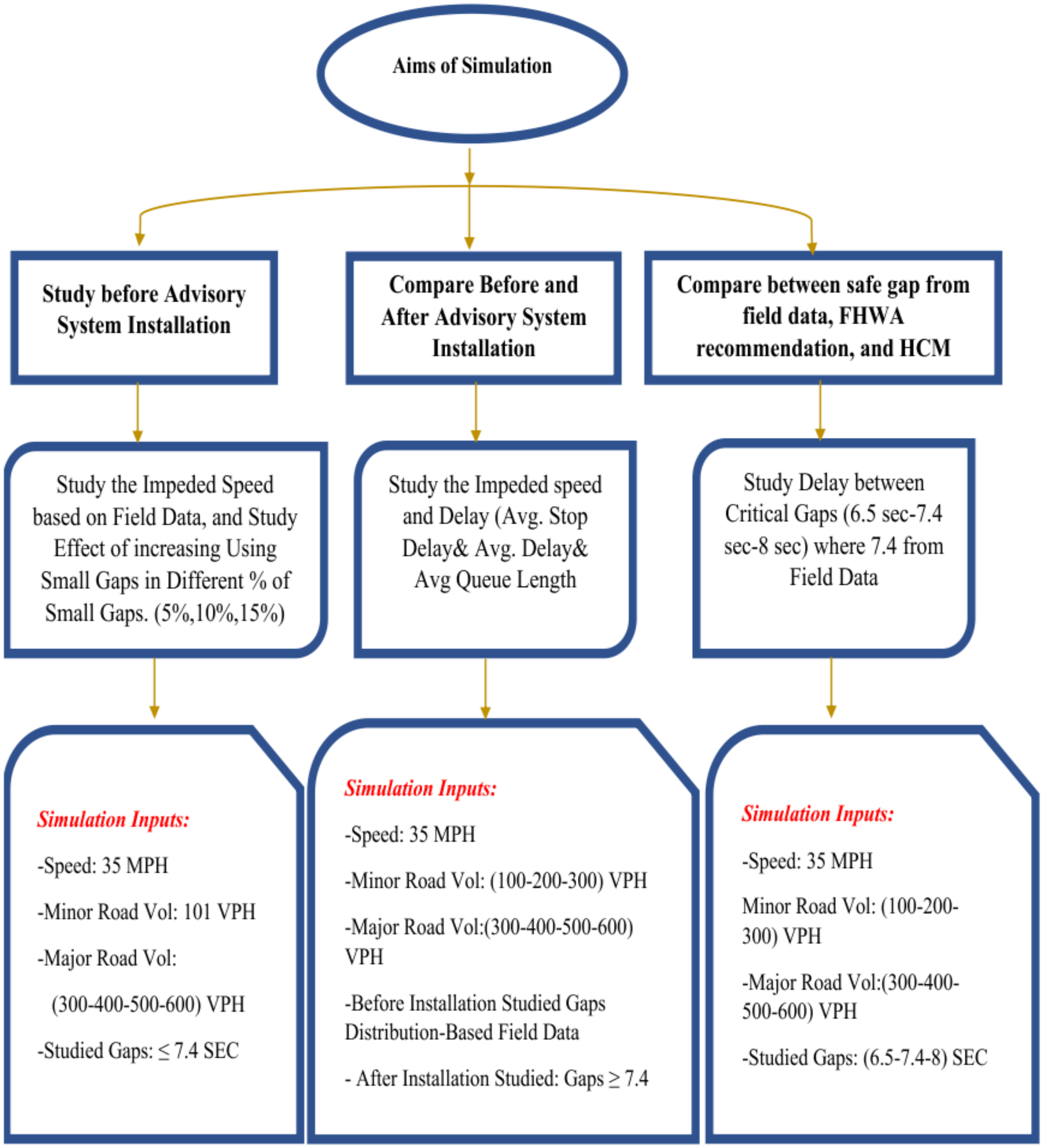

Figure V.7 – Simulation Plan

E. Simulation Results

The simulation was made for discerning the subjects that were not easy to do on-site. Besides that, simulation also helped in studying different scenarios like different volumes in minor and major roads. Moreover, simulation also assisted in studying the existing situation at the intersection, specifically in terms of recognizing the importance, advantages, and efficiency of the new advisory system. Most importantly, simulation also enabled the study of the changes that occurred after installing the advisory system.

As mentioned in the previous sections, site field chapter, a reduction in older drivers' sensory and cognitive processing ability as well as motor skills lead to their selection of unsafe smaller gaps. There are two significant issues in selecting smaller gaps than required for older drivers. The first issue is safety, where if the major road vehicles cannot stop, it can lead to accidents. The second issue is associated with travel impedance. When a smaller gap is used, a sudden reduction in the speed of the oncoming major road vehicle to avoid a crash results in unwanted traffic slowdown, which may also cause collisions among the other major road vehicles.

Thus, the simulation cases have included different volume levels on the major and minor roads. In addition, different critical gap values, recommended by FHWA and HCM, have also be tested in the simulation. Table V-1 illustrates input considerations of the simulations.

Table V-1 Simulation Inputs

Inputs	Before Installation	After Installation	Stow Intersection Existing Situation
Speed (MPH)	35	35	35
Minor Road Volume (VPH each direction)	100-200-300	100-200-300	101
Major Road Volume (VPH each direction)	300-400-500-600	300-400-500-600	400
Studied Gaps (Sec)	≤ 7	12≥ Gaps ≥7.4	≥3

1. Results Before Advisory System Installation

From field data, the percentage of older drivers who selected small gaps is about 5%. Therefore, this research started from 5% and increased the number to 10% and 15%. The results show that the percentage of impeded speed incidents increases with an increased number of older drivers who select small gaps.

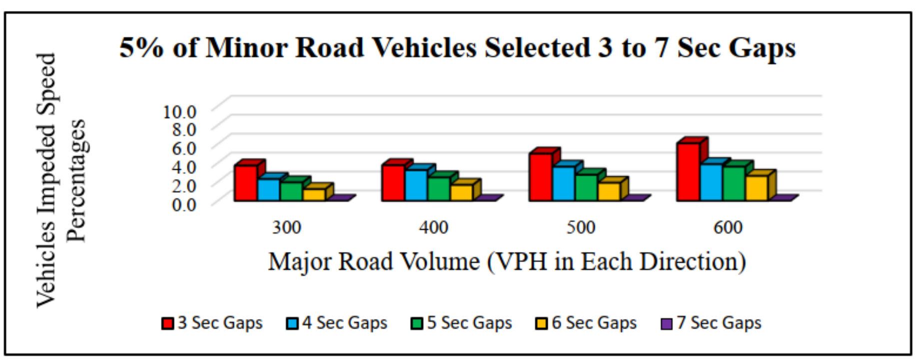

Figure V.8 - Impeded Speed Percentages When 5% of Older Drivers select small gaps

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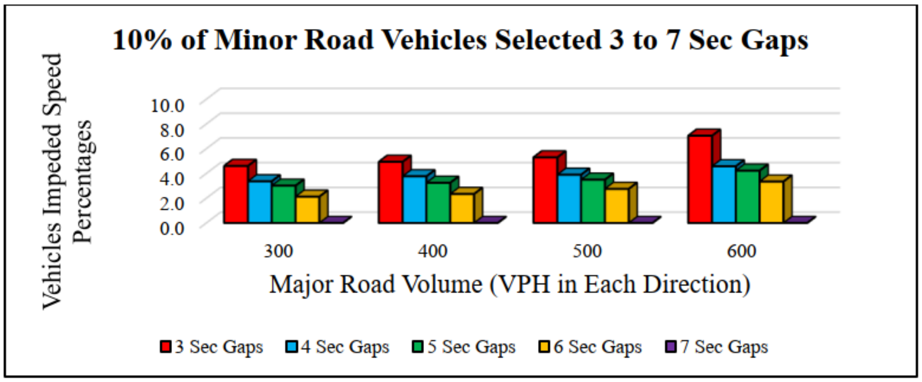

Figure V.9 - Impeded Speed Percentages When 10% of Older Drivers select small gaps

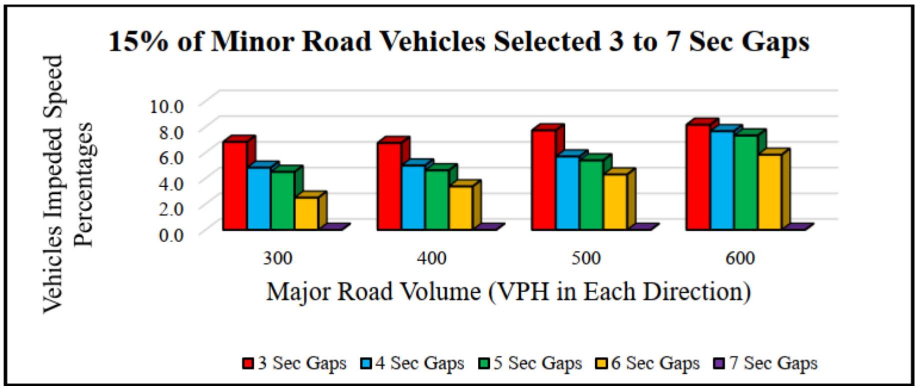

Figure V.10 - Impeded Speed Percentages When 15% Older Drivers select small gaps

Figure V.8, Figure V.9, Figure V.10 show that the impeded speed incidents decrease when older drivers select a longer gap. Such incidents can be totally avoided (i.e., zero percent) when the gap size is seven seconds or longer. If the number of older drivers selecting small gaps increases, the percentage of impeded speeds becomes greater. This will affect traffic operation on the major road, indicating a growing potential for traffic accidents. The seven-second gap time seems to have satisfied the needs of older drivers, because it is approximately the same value as the safe gap discussed in the previous section of the report, developed from the field data.

From the above figures, it can also be observed that the percentage of impeded speeds increased with the traffic volume on the major road. Further, the number of older drivers selecting smaller gaps plays as another major influencing factor to impeded speeds. It can be clearly seen that a higher percentage of older drivers selecting gaps smaller than the safe gaps can lead to drastically increased impeded speed incidents.

2. Comparing Results Before and After Advisory System Installation

Figure V.11 to Figure V.25 show details in support of the comparison of MOEs, including average delay, average stopped delay and average queue length, before and after the installation of the safety advisory system. Different volumes, 100~300 VPH on the minor road and 300~600 VPH on the major roads, are used in the comparison.

a. Impeded Speed

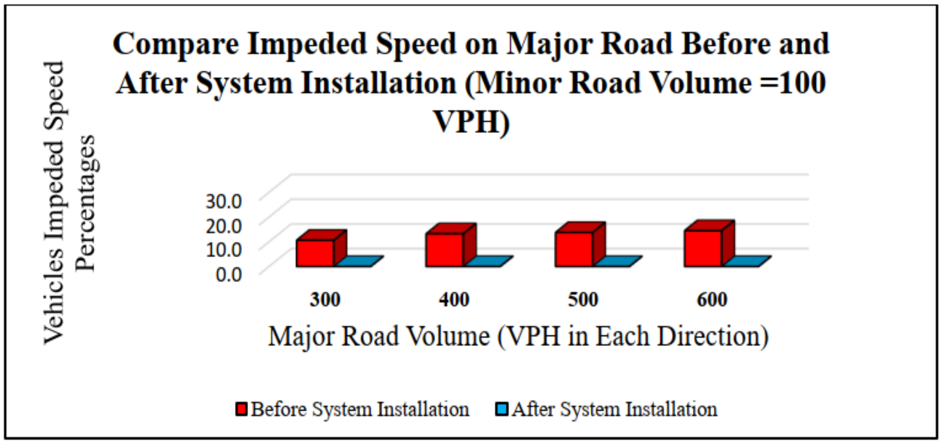

Figure V.11 - Impeded Speed Percentages Before and After System Installation at 100VPH on Minor Road

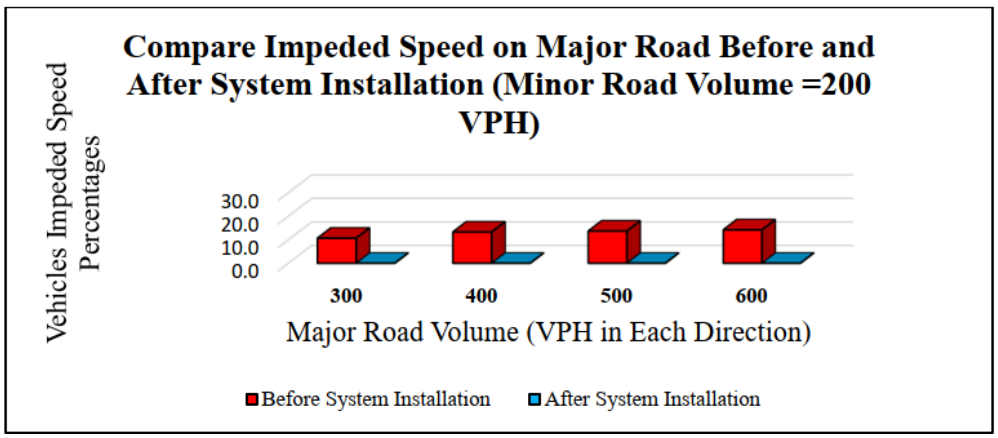

Figure V.12 - Impeded Speed Percentages Before and After System Installation at 200VPH on Minor Road

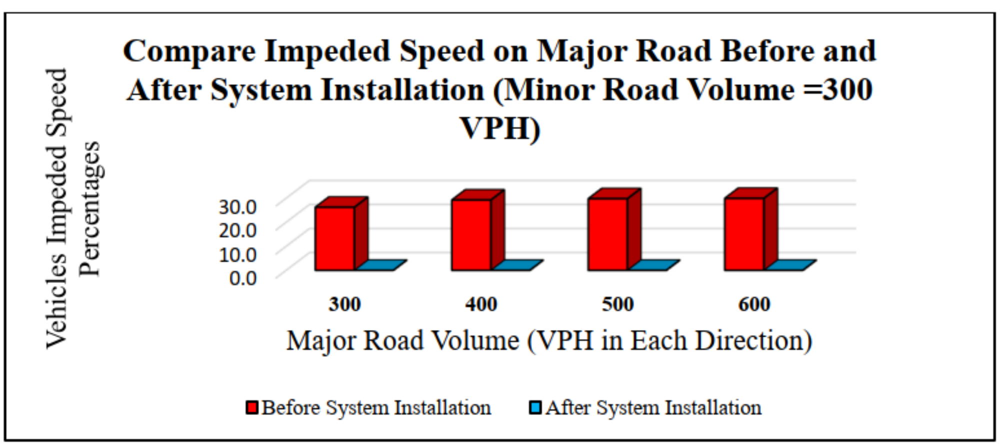

Figure V.13 - Impeded Speed Percentages Before and After System Installation at 300VPH on Minor Road

As shown in Figures V.11, V.12, and V.13, the impeded speed incidents change at different volumes on the major and minor road.

The impeded speed percentage, before system installation, slightly increases when the minor road volume is 100 VPH and 200 VPH and experience a sharp increase at minor road volume of 300 VPH. The impeded speed percentage also increases with the major road volume.

In Figure V.11, the impeded speed percentage, before system installation, ranges from 9% at 300 VPH to 13% at 600 VPH on the major road. Similarly, Figure V.12 shows that, the impeded speed percentage, before system installation, ranges from 10% at 300 VPH to 14% at 600 VPH on the major road. Those numbers increased from 23% to 29% on the major road when the minor road volume reaches 300 VPH.

b. Average Delay on Major Road After System Installation

The effects of low, median, and high volumes are considered on the major and the minor roads, and the results are shown in Figure V.14 through Figures V.17.

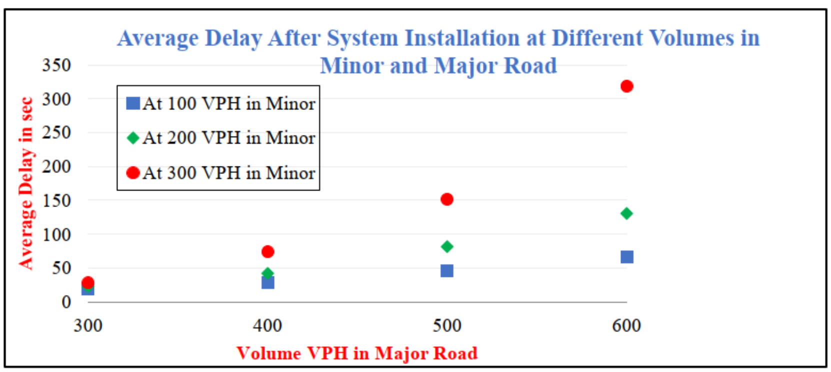

Figure V.14 - Average Delay on Major Road After System Installation at Different Volumes on Minor Road

Figure V.14 depicts that the average delay increases with the traffic volume. The average delay at a low volume range on the major and minor roads experiences a slight increase; however, a dramatic increase can be seen when the volume level has increased 600 VPH on the major road 300 VPH on the minor road.

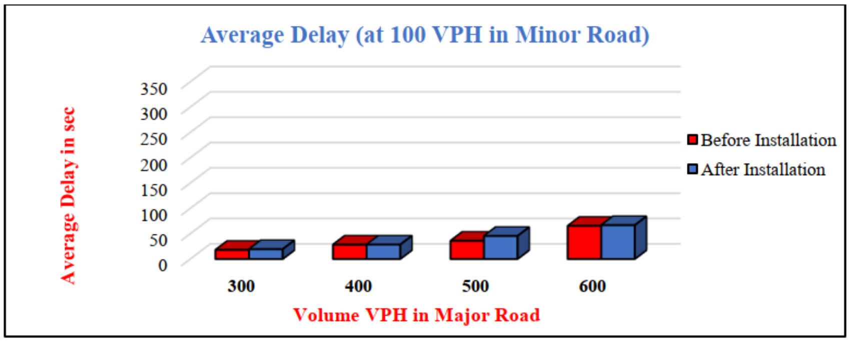

Figure V.15 - Average Delay on Major Road Before and After System Installation at 100 VPH on Minor Road

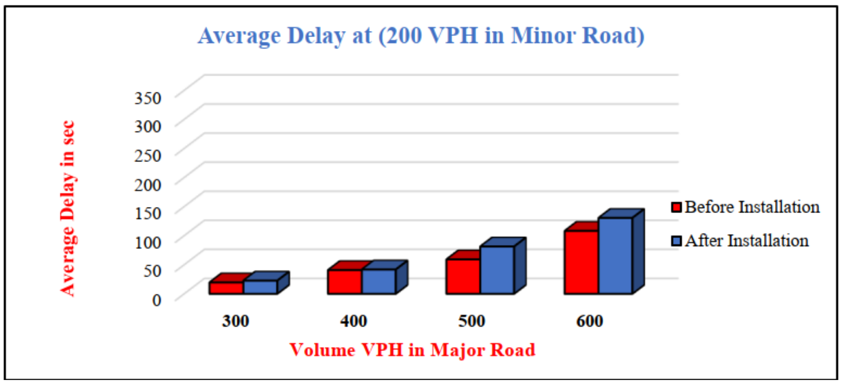

Figure V.16 - Average Delay on Major Road Before and After System Installation at 200 VPH on Minor Road

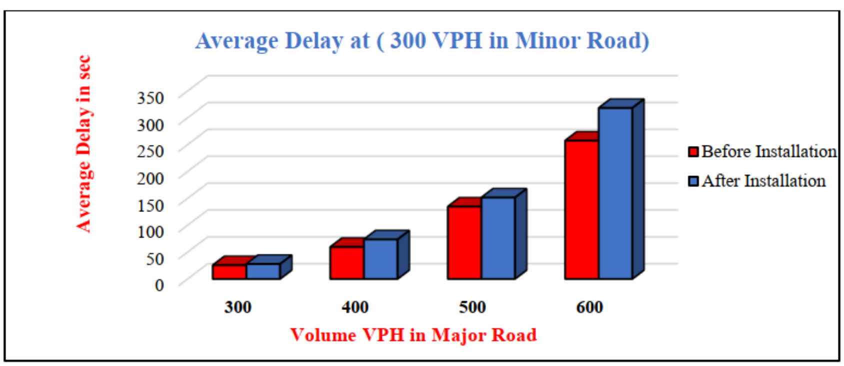

Figure V.17 - Average Delay on Major Road Before and After System Installation at 300 VPH on Minor Road

c. Average Stopped Delay on Minor Road After System Installation

The average stopped delay per vehicle in seconds is the average time for each vehicle that is waiting for a gap to join the major road traffic.

Figure V.18 represents the average stopped delay after system installation, at different volumes on the minor and major roads.

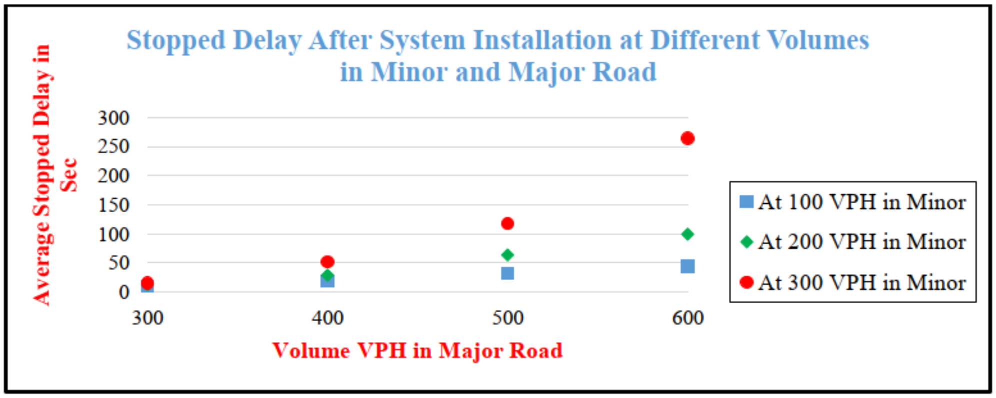

Figure V.18 - Stopped Delay on Minor Road After System Installation at Different Volumes

The results show that, when the minor road traffic volume is low, the stopped delay increased slightly when the traffic volume on the major road changed from 300 VPH to 400 VPH. This delay increased more quickly when the minor road volume changed from 200 VPH to 300 VPH. Similarly, they also show that a higher traffic volume on the major road leads to a drastic increase on the minor road vehicles. Figure V.19, Figure V.20, and Figure V.21 show specific changes in each of the aforementioned cases.

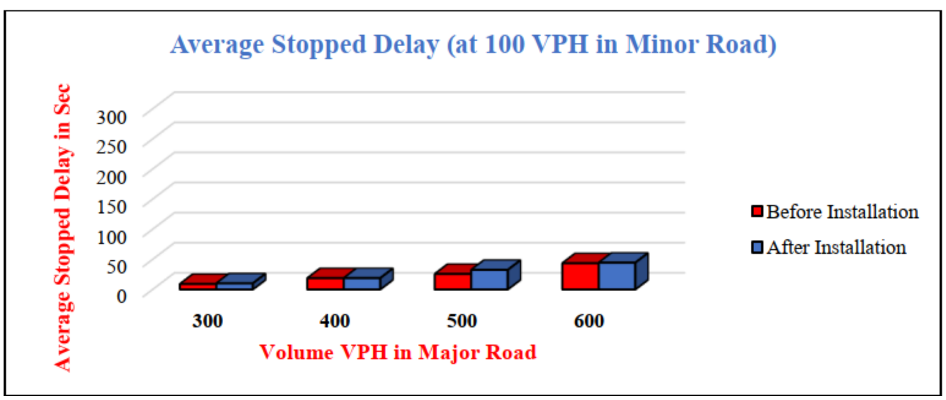

Figure V.19 - Stopped Delay on Minor Road Before and After System Installation at 100 VPH on Minor Road

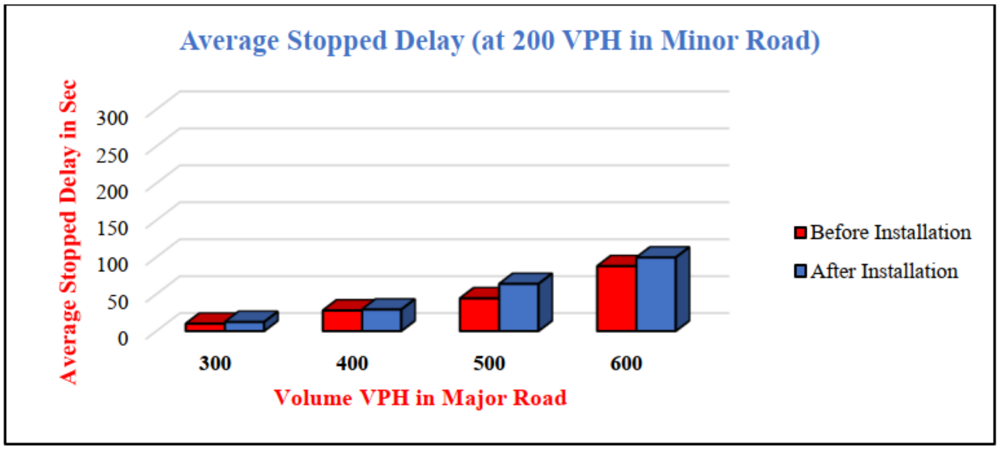

Figure V.20 - Stopped Delay on Minor Road Before and After System Installation at 200 VPH on Minor Road

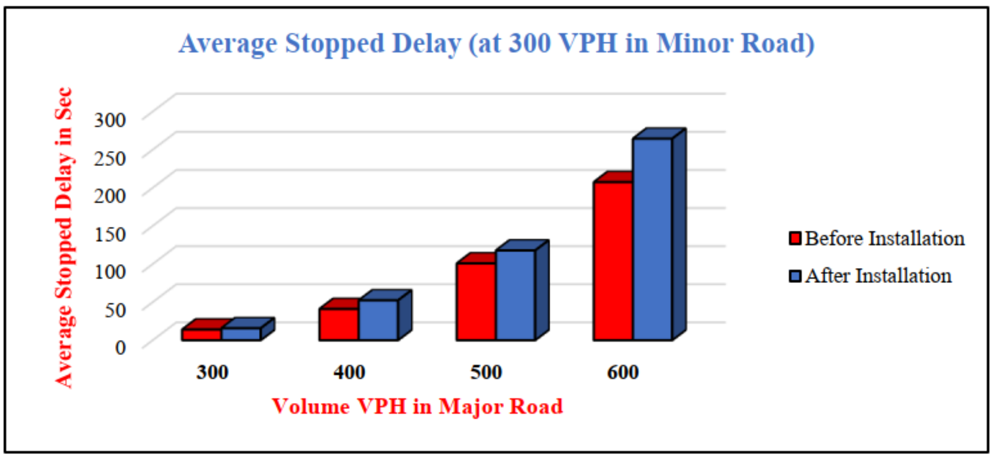

Figure V.21 - Stopped Delay on Minor Road Before and After System Installation at 300 VPH on Minor Road

d. Comparing the Average Queue Length After System Installation at different Minor and Major Road Volumes

Figure V.22 shows that the average queue length, after system installation, is minimal at small volumes on the minor and major roads, but it is gradually increasing with the volumes on the minor and major roads. Following a similar pattern to those of impeded speeds and delays, it also shows a drastic increase in queue length when the minor road volume reaches 300 VPH facing 500 VPH on the major road.

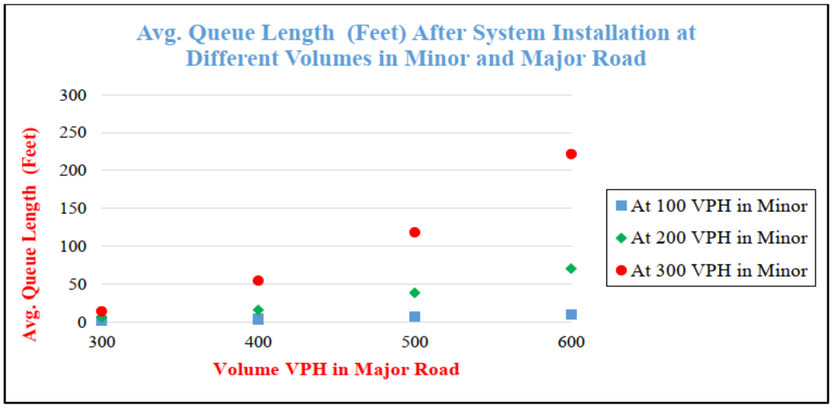

Figure V.22 - Avg. Queue Length After System Installation at Different Volumes on Minor Road

Figure V.23, Figure V.24, and Figure V.25 show the detail changes of the queue length on the minor road before and after the system installation. The comparison shows that, at extreme volume levels, the queue length is 180 feet before and 229 feet after system installation.

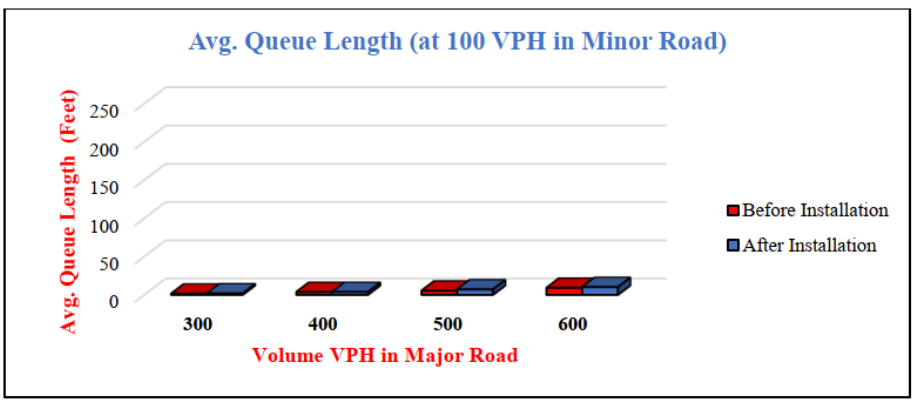

Figure V.23 - Avg. Queue Length Before and After System Installation at 100 VPH on Minor Road

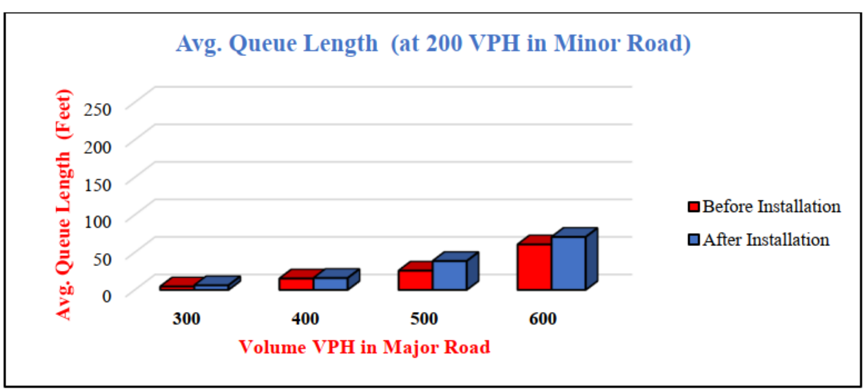

Figure V.24 - Avg. Queue Length Before and After System Installation at 200 VPH on Minor Road

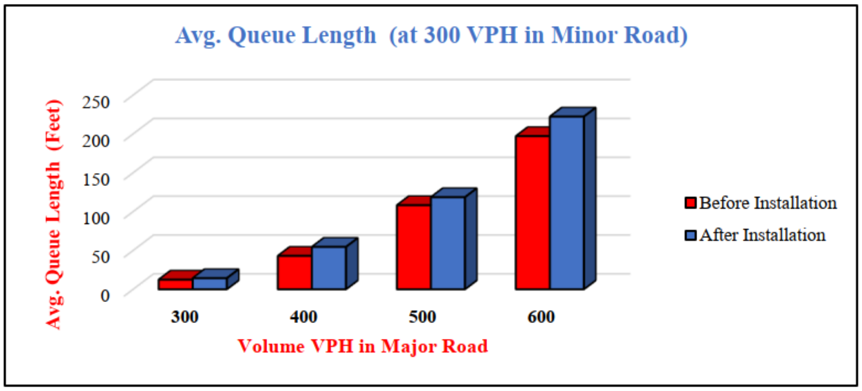

Figure V.25 - Avg. Queue Length Before and After System Installation at 300 VPH on Minor Road

3. Results Comparison Using 6.5 seconds, 7.4 seconds, 8 seconds as Safe Gap

As discussed in the previous section, the FHWA's recommended minimum safe gap-critical gap for older drivers to be at least eight seconds. On the other hand, the Highway Capacity Manual uses 6.5 seconds on average for all ages. Moreover, the calculated critical gap from our field data for older drivers is 7.4 Seconds. Therefore, in this part of work, an effort has been made to compare the MOEs (Average Delay, Average Stopped Delay, and Average Queue Length) between the results from using each of those different safe gap values.

a. Delay Comparison Under Different Safe Gaps

Figure V.26, Figure V.27, and Figure V.28 show slight differences between the three safe gap options when traffic volume is at 300 VPH. The average delay at volume 600 VPH on the major road is much higher than at other volumes when the 8-second gap is used. The 7.4-second field data estimated gap size results in similar output, but the corresponding average delay is more moderate than the 8 second-gap case.

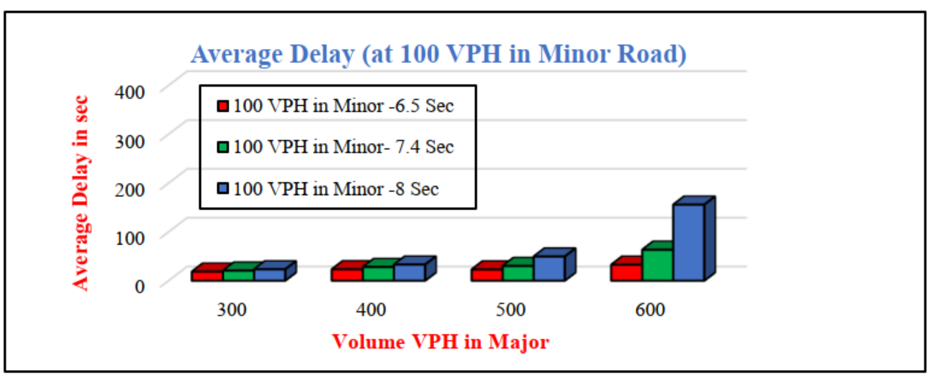

Figure V.26 - Average Delay for Different Safe Gaps at 100 VPH on Minor Road

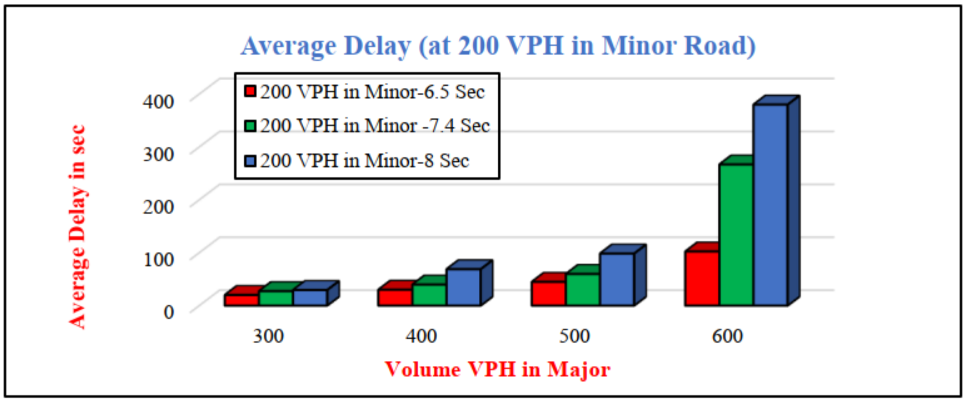

Figure V.27 - Average Delay for Different Safe Gaps at 200 VPH on Minor Road

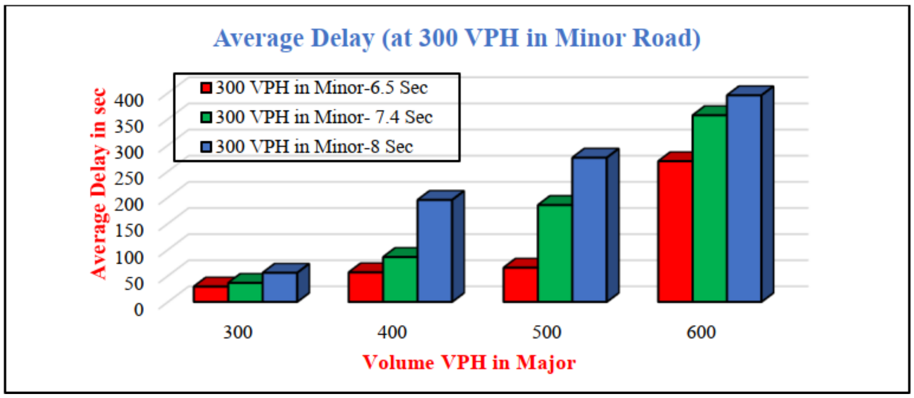

Figure V.28 - Average Delay for Different Safe Gaps at 300 VPH on Minor Road

Figure V.29, Figure V.30, and Figure V.31 show the average stopped delay by minor road vehicles at different volume levels on the major road. Similar observations can be made from the details that, at low volumes, the average stopped delay experiences little changes; however, major variations in stopped delay can be found when the traffic volume grows to 300 VPH on the minor road, looking for gaps to merge into the major road with a traffic volume of 600 VPH. The 7.4-second option brings about better results than the 8 second option.

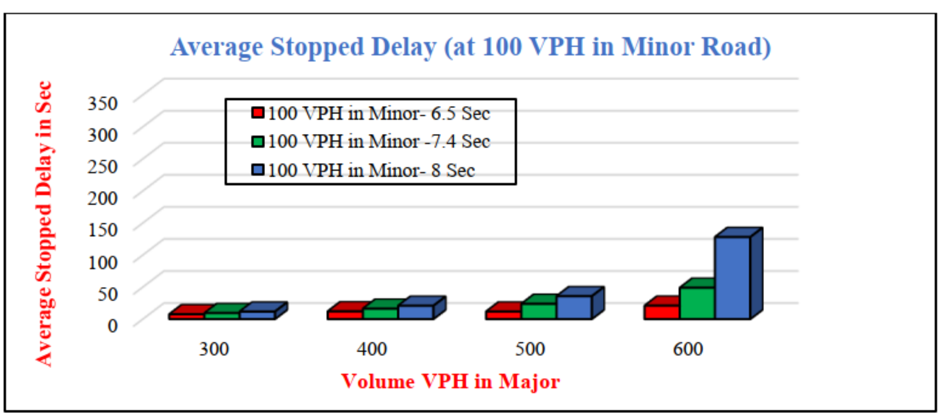

Figure V.29 - Average Stopped Delay for Different Safe Gaps at 100 VPH on Minor Road

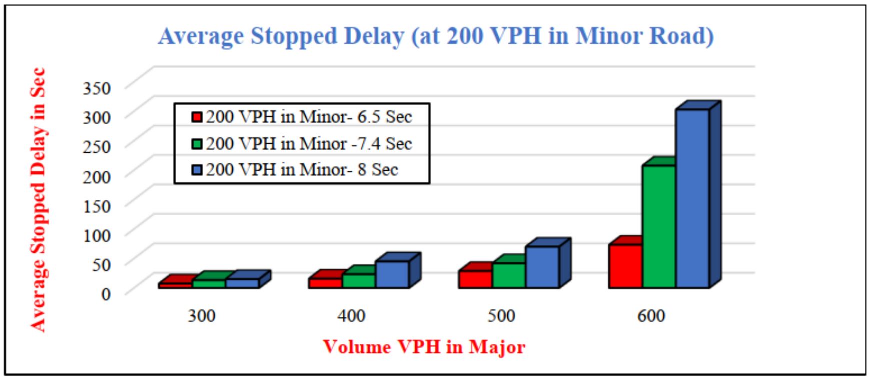

Figure V.30 - Average Delay for Different Safe Gaps at 200 VPH on Minor Road

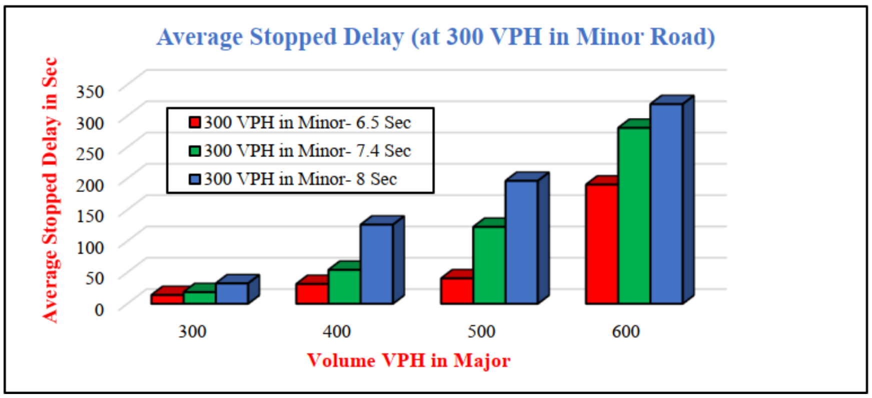

Figure V.31 - Average Delay for Different Safe Gaps at 300 VPH on Minor Road

Figure V.32, Figure V.33, and Figure V.34 show the changes in average queue length at different levels of traffic volume. Again, a similar pattern to those on delay comparison is found.

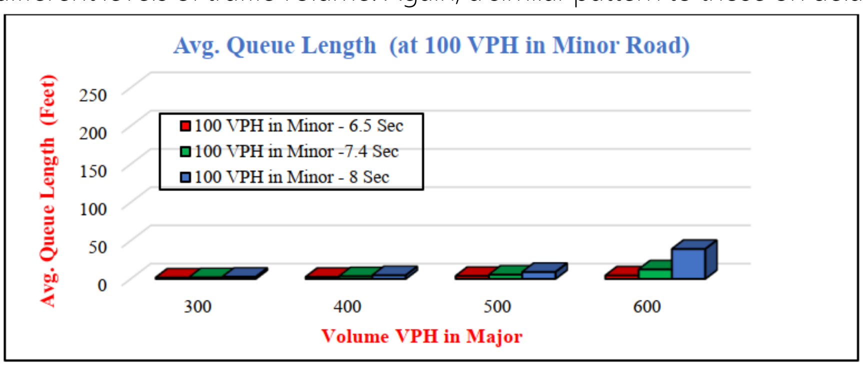

Figure V.32 – Queue Length for Different Safe Gaps at 100 VPH on Minor Road

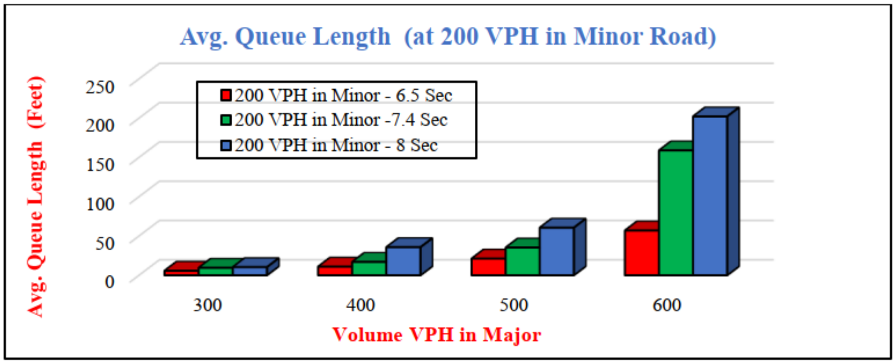

Figure V.33 – Queue Length for Different Safe Gaps at 200 VPH on Minor Road

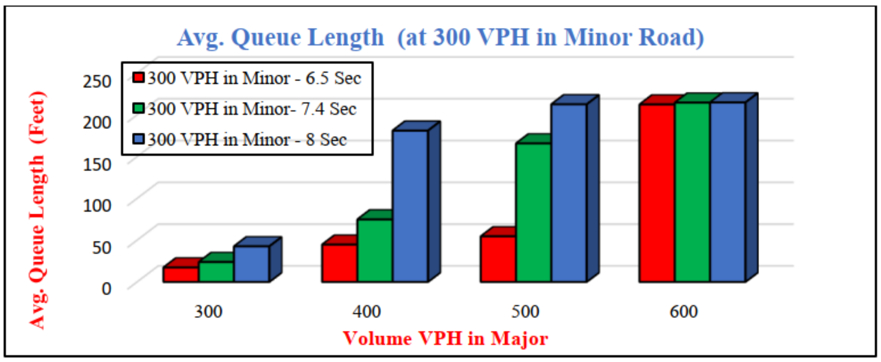

Figure V.34 – Queue Length for Different Safe Gaps at 300 VPH on Minor Road

4. Summary of Simulation

This research aims to improve safety for older drivers at stop-controlled T intersections without significantly affecting traffic operation on the major and minor roads. The proposed advisory system relies on using a properly selected safe gap (critical gap) for the intersection to not only enhance safety but also maintain operational efficiency. The simulation results have shown that at low traffic volumes, the impact on traffic operations by the proposed advisory system is at a minimum level. For a moderate to high traffic volume situation on the major and minor roads, the average delay, average stopped delay, and average queue length at worse scenarios are increased between 10% to 20% after installing the advisory system. Thus, there is a trade-off between safety and efficiency, considering the benefit of using a field data based safe gap to operate the advisory system, including the total avoidance of impeded speeds to the major road vehicles.

VI. FIELD TEST AND DISCUSSION

The elderly population is rapidly growing, and the majority of them prefer using vehicles as their primary mode of transportation. The proposed advisory system is designed and tested to assist older drivers in gap selection at unsignalized T intersections. The field test was conducted at the Fishcreek test location in Stow, Ohio, and a total number of 79 old drivers (60 males: 19 females) completed the study safely. It is important to note that among the selected participants, 38 were in the controlled situation and 41 were in the uncontrolled situation (difference discussed in the previous section). The research has clearly shown that the warning messages, such as, beeping alone, beeping with red flashing, are effective means of communication with older drivers, but LCD based messages are less preferred. In particular, 62% of the participants considered beeping combined with flashing as the most effective warning option. The following sections describe the results analysis and statistical testing.

A. Field Test Results

Two parts of work were included in the field work. The first part was done at an early stage of the project, and it is related to gaps distribution and critical gap estimation to build the model. That part of work has been discussed in the previous section, so the main focus in this section is on the second part, which is the actual testing of the safety advisory system involving older driver participants.

1. Gap Distribution and Critical Gap

The field test results showed some differences in gap distribution between the two test sites, especially with respect to the gap sizes. For example, at the second test site, the critical gap value was found to be 6.5 seconds, smaller than 7 seconds. The main reason for the older drivers to select smaller gaps at this location is that the volume level on the major road at the Tallmadge location is higher than at the Stow location. Figures VI.1 and VI.2 show additional details.

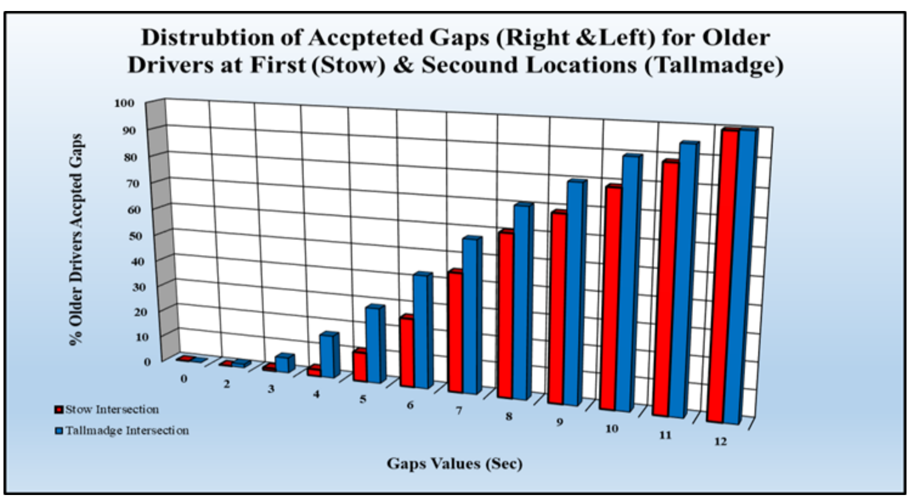

Figure VI.1 - Difference in Gap Distribution Between Two Test Sites

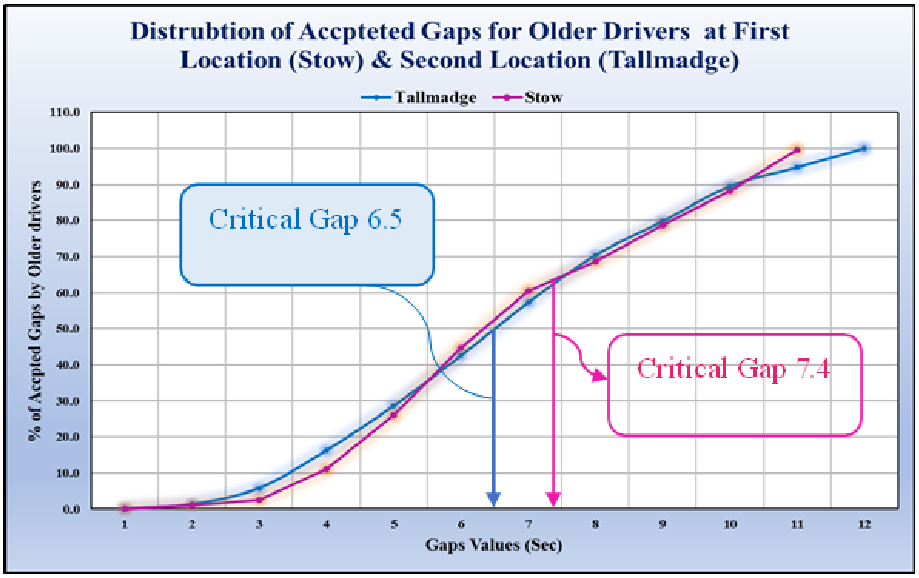

Figure VI.2 - Critical Gap for Tallmadge vs. Stow Locations

The above results indicate that the critical gap may vary from one intersection to another and, for the purpose of implementing the safety advisory system, it is crucial to find the critical gap using the local data.

2. Testing the Advisory System at Fishcreek Site

After the system installation at the intersection, the test in the controlled vs. uncontrolled situation was performed. The test started with the participants driving their vehicles, in which the communication and warning device was installed, to the minor road approach making either a left or right turn. Upon reaching the intersection, if the next gap is unsafe, the in-vehicle device immediately received a warning in the form of either beeping, a red flashing, or a message on the LCD screen. The participant was observed over his/her decision about this gap, either to follow the warning and reject the gap or still accept it. The experiment was repeated for each participant, instructed to make a left or right turn at the intersection, so that the system could be fully evaluated by the participant.

The selected participants were 60 years or older. This assessment is based on the age requirement at the senior facility and the best judgement by the onsite project team. Among the selected participants, 24.1% were females, and 75.9% were males (see Figure VI.3). Each participant was tested not only making both left and right turns, but also serving both the controlled situation and uncontrolled situation (Table VI-1).

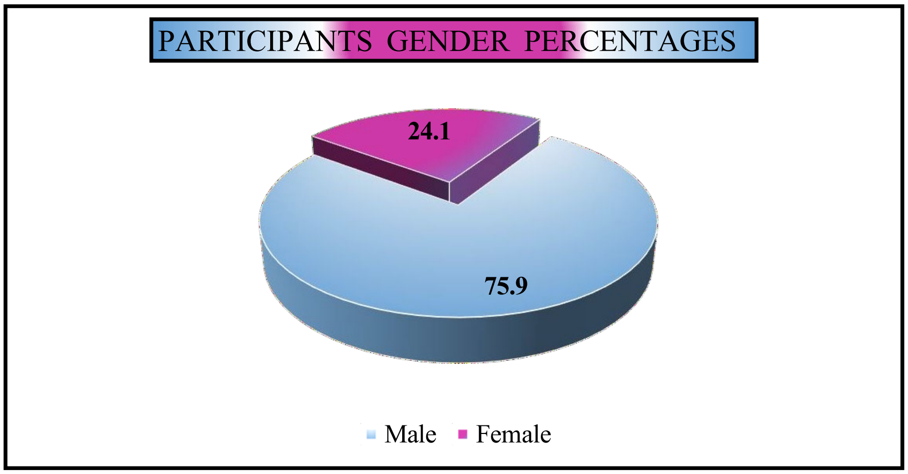

Figure VI.3 - Gender Composition of Participants

Table VI-1 Field Test Data Summary

System Type	Direction	Participants Prefer Flashing	Participants Prefer Beeping	Participants Prefer LCD	Participants Prefer (Flashing+Beeping)	Participants Prefer (Beeping+LCD)	Participants Prefer (Flashing+LCD)	Total of Participants	Participants Follows the Device Warning and Safe Test Completions	Participant Need Larger Gap than Safe Gap	Participants not affecting the traffic operation
Uncontrol Situation	Right Turn	21	17	3	18	2	4	41	38	3	41
	Left Turn	18	20	3				41			
Control Situation	Right Turn	19	12	7	18	4	3	38	36	2	38
	Left Turn	16	22	0				38			
Total		74	71	13	36	6	7	158	74	5	79

At the end of the test, two simple questions were asked to the participants. The first question was about their opinion regarding safety when using the advisory system, and the second about the best warning message type by the advisory system. The results are presented in Table VI-2. Then, the SPSS software was used to statistically analyze the results and help understand the complex data.

Table VI-2 Participants Answers Summary

Questions	Answers Options	Percentages Responses
Question 1:		
Is the System Useful and Improved Safety?	Useful and Improved Safety	76
	No Difference with or without	3
	Unsafe to Use	0
Question 2:		
What is the Best Waring Type when Using the Advisory System?	Prefer Beeping	14
	Prefer Red Flashing	16
	Prefer LCD Message	0
	Prefer a Combination of Warnings	49

a. Question 1: Is the System Useful and Can Improve Safety?

The participants were provided with three options to respond to the first question. These options included: helpful and improved safety, no difference with or without the system, and unsafe to use the system. The participants were also provided with four options to answer the second question, including, prefer beeping, prefer red flashing, prefer LCD message, or prefer a combination of warnings.

Three participants stated that there is no difference using the device or not using it. A follow-up conversation with them revealed this is mainly due to the lack of participants' trust in new technology and high confidence on their driving skills. Seventy-six participants, representing 96.2% of the total participants showed satisfaction towards using the advisory system and found it beneficial for improved safety. However, none of the participants mentioned that the advisory system is unsafe to use, as indicated in Figure VI.4.

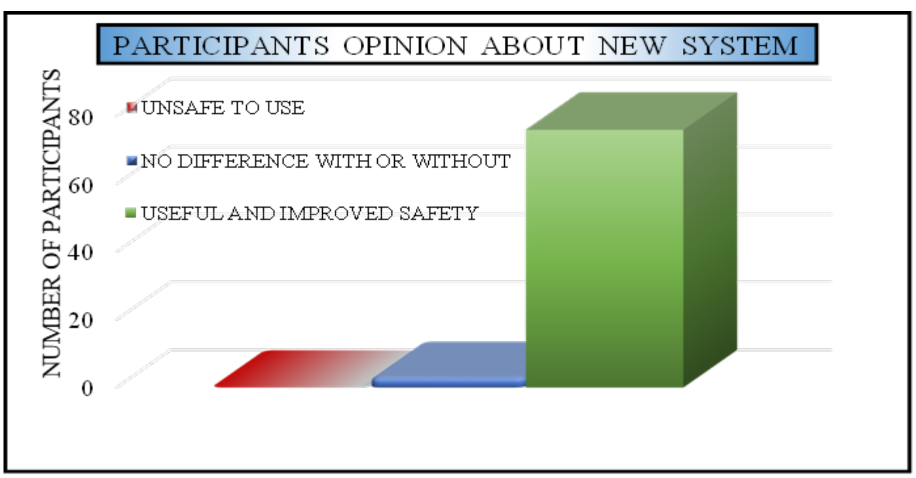

Figure VI.4 - Participants Opinion about New System

The statistical tests looked into the correlations between gender, age, right turn, and left turn over their opinions of the system to improve safety.

Gender vs. Improved Safety

Null hypothesis (H_0): There is no difference between male and female in perceptions towards the effectiveness of the advisory system to improve safety.

Table VI-3 Gender vs. Improved Safety Crosstabulation

			Improved safety		Total
			Advisory system useful and improved safety	No difference with or without using advisory system	
Gender	Male	Count	58	2	60
		% of Total	73.40%	2.50%	75.90%
	Female	Count	18	1	19
		% of Total	22.80%	1.30%	24.10%
Total		Count	76	3	79
		% of Total	96.20%	3.80%	100.00%

Table VI-4 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	0.147[a]	1	0.701		
Continuity Correction[b]	0	1	1		
Likelihood Ratio	0.137	1	0.711		
Fisher's Exact Test				0.567	0.567
Linear-by-Linear Association	0.145	1	0.703		
N of Valid Cases	79				

a. 2 cells (50.0%) have an expected count of less than 5. The minimum expected count is 0.72.

b. Computed only for a 2x2 table

As shown in Table VI-3, 73.4% of male participants think the new advisory system is useful and helps improve safety. On the other hand, 2.5% said that they are indifferent over the effectiveness of the system. In contrast, 22.8% of the females also think that the new advisory system will be useful for improving safety compared to only 1.3% who believe that there is no difference. However, the chi-square test results (Table VI-4) clarify that there is no statistically significant difference between the perception of males and females towards the effectiveness of the system (p value >0.05).

System type and Improved Safety

Null Hypothesis (H_o): There is no difference between uncontrolled and control situations in perceptions to improve safety.

Table VI-5 System Type vs. Improved Safety Crosstabulation

			Improved safety		Total
			Advisory system useful and improved safety	No difference with or without using advisory system	
System Type	Uncontrol	Count	41	0	41
		% of Total	51.90%	0.00%	51.90%
	Control	Count	35	3	38
		% of Total	44.30%	3.80%	48.10%
Total		Count	76	3	79
		% of Total	96.20%	3.80%	100.00%

Table VI-6 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.365[a]	1	0.037		
Continuity Correction[b]	1.551	1	0.213		
Likelihood Ratio	4.519	1	0.034		
Fisher's Exact Test				0.107	0.107
N of Valid Cases	79				

a. 2 cells (50.0%) have an expected count of less than 5. The minimum expected count is 1.44.

b. Computed only for a 2x2 table

Table VI-5 shows that those who consider the new advisory system useful, in terms of improving safety, consist of over 96% of the entire sample population, split into uncontrolled (51.9%) and controlled (44.3%) groups. However, 3.8% of the participants from the controlled group consider no difference using or not using the technology. Table VI-6 presents a Chi-Square test which suggests a statistically significant variation between uncontrolled and controlled groups, related to their opinion on safety improvement (p value < 0.05). By looking at the data, it appears that the reactions from the controlled group are not as satisfactory as the uncontrolled group.

Best Message Type vs. Safety Improvement for Right turn

Null Hypothesis (H_0): There is no significant association between the best warning message type and its effectiveness in improving safety when turning right.

Table VI-7 Best Message Type vs. Improved Safety for Right Turns Crosstabulation

			Improved safety		Total
			Advisory system useful and improved safety	No difference with or without using advisory system	
Best Option in Right	Flashing	Count	41	2	43
		% of Total	51.90%	2.50%	54.40%
	Beeping	Count	29	0	29
		% of Total	36.70%	0.00%	36.70%
	LCD	Count	6	1	7
		% of Total	7.60%	1.30%	8.90%
Total		Count	76	3	79
		% of Total	96.20%	3.80%	100.00%

Table VI-8 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.338[a]	2	0.188
Likelihood Ratio	3.59	2	0.166
N of Valid Cases	79		

a. 3 cells (50.0%) have an expected count of less than 5. The minimum expected count is 0.27

It can be seen from Table VI-7 that among the respondents who took the right turn, 51.9% of them liked flashing as the best warning option to improve safety. On the other hand, 36.7% of them considered beeping as the best warning option, whereas only 7.6% chose LCD as the best warning option. However, the chi-square test presented in Table VI-8 supports the finding that there is no statistically significant variation between the ideal warning option and safety improvement option when turning right.

Best Message Type vs. Safety Improvement for Left Turn

Null Hypothesis(H_0): There is no significant association between best warning type and its effectiveness in improving safety when turning left.

Table VI-9 Best Message Type vs. Improved Safety for Left Turn Crosstabulation

			Improved safety		Total
			Advisory system useful and improved safety	No difference with or without using advisory system	
Best Option in Right	Flashing	Count	27	0	27
		% of Total	34.20%	0.00%	34.20%
	Beeping	Count	44	3	47
		% of Total	55.70%	3.80%	59.50%
	LCD	Count	5	0	5
		% of Total	6.30%	0.00%	6.30%
Total		Count	76	3	79
		% of Total	96.20%	3.80%	100.00%

Table VI-10 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.123[a]	2	0.006
Likelihood Ratio	3.196	2	0.202
Likelihood Ratio	0.729	1	0.393
N of Valid Cases	79		

Table VI-9 shows that among the respondents who take a left turn, 55.7% of them chose beeping as the best warning option. Around 34.2% chose flashing as the best warning option instead, and 6.3% of them selected LCD instead as the best warning option. The chi-square test presented in Table VI-10 statistically shows that there is a significant variation between the best types of warning message for vehicles turning left. More investigations are needed to explain this finding.

b. Question 2: What is the best type of warning message from the advisory system?
For the second question, over 49 participants prefer a combination of beeping and flashing, representing over 62 % of the total sample. However, 16 participants - accounting for 20% of the total sample, preferred red flashing as the best type of warning. Only 14 participants that account for 17.7% of the total sample liked beeping as the best warning type, as shown in Figure VI.5.

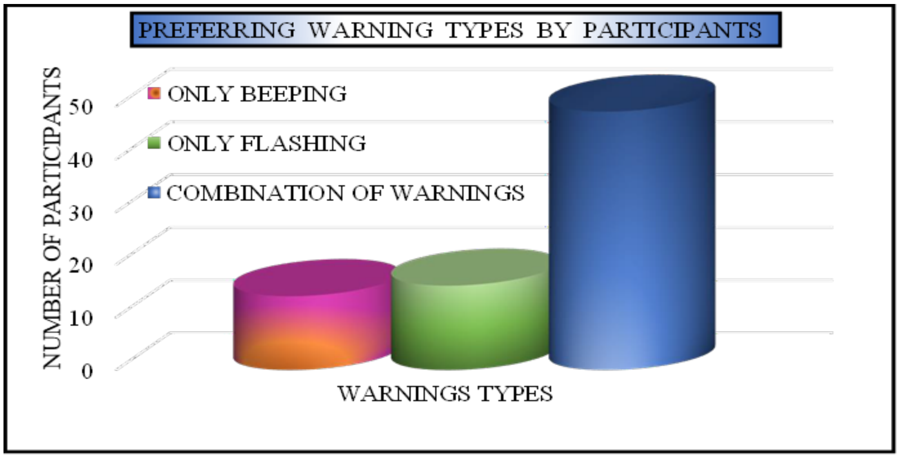

Figure VI.5 - Preferring Warning Types by Participants

Among the total sample, 8.86% of the participants preferred a combination of red flashing and messages on the LCD. Conversely, 7.59% of the participants chose a combination of beeping and message on the LCD as the best option (see Figure VI.6).

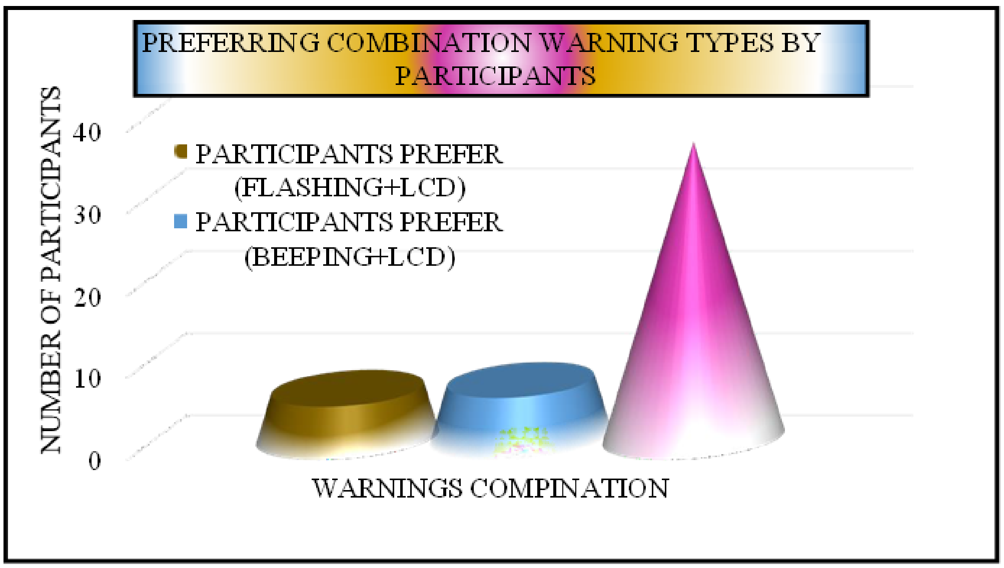

Figure VI.6 - Preferred Combination Warning Types by Participants

This research further looked into the possible correlation between gender, age, and type of system control (controlled situation or uncontrolled), with the best warning type selected.

Gender vs. Best Warning Type

Null hypothesis (H_0): This is no difference between gender and the best warning type.

Table VI-11 Gender vs. Best Warning Type Crosstabulation

			Best Warning Type When Using Advisory System			Total
			Only Flashing	Only Beeping	Combination of Warnings	
Gender	Male	Count	9	9	42	60
		% of Total	11.40%	11.40%	53.20%	75.90%
	Female	Count	7	5	7	19
		% of Total	8.90%	6.30%	8.90%	24.10%
Total		Count	16	14	49	79
		% of Total	20.30%	17.70%	62.00%	100.00%

Table VI-12 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.000[a]	2	0.09
Likelihood Ratio	6.792	2	0.034
N of Valid Cases	79		

a. 2 cells (50.0%) have an expected count of less than 5. The minimum expected count is 3.37.

As depicted in Table VI-11, 53.3% of the male participants consider the combination of warnings (both flashing and beeping) as the best warning type. Only 11.4% of the male participants consider either flashing or beeping as the best warning option.

Amongst the females, 8.9% chose only flashing, or a combination of flashing and beeping, as their best warning option. However, a test result of chi square shows that there is no statistically significant difference between males and females regarding the best warning type (p value >0.05) (Table VI-12).

Type of Control vs. Best Warning Type

Null Hypothesis (H_o): There is no difference between uncontrolled and controlled situations in selecting the best warning type.

Table VI-13 Type of Control vs. Best Warning Type Crosstabulation

			Best Warning Type When Using Advisory System			Total
			Only Flashing	Only Beeping	Combination of Warnings	
System Type	Uncontrol	Count	9	8	24	41
		% of Total	11.40%	10.10%	30.40%	51.90%
	Control	Count	7	6	25	38
		% of Total	8.90%	7.60%	31.60%	48.10%
Total		Count	16	14	49	79
		% of Total	20.30%	17.70%	62.00%	100.00%

Table VI-14 Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	0.443[a]	2	0.801
Likelihood Ratio	0.444	2	0.801
N of Valid Cases	79		

a. 0 cells (00.0%) have an expected count of less than 5. The minimum expected count is 6.73.

Table VI-13 shows that the individuals who consider the combination of both, flashing and beeping, as the best type of warning options are most represented in both the uncontrolled (30.4%) and controlled (31.6%) groups. In comparison, 8.9% of the participants from the controlled group and 11.4% from the uncontrolled group chose only flashing as their best message type. Table VI-14 suggests that there is no statistically significant variation between uncontrolled and controlled groups regarding the best type of warning message.

It should be pointed out that, around 93.7% of the total participants followed the advisory system's warning to reject the unsafe gaps. Only 6.3% of the participants (5 participants) waited longer after the end of the warning message because they preferred to use an even larger gap than the safe gap used by the warning system, as shown in Figure VI.7. Furthermore, there have been no impeded speed incidents found from all the participants to the experiment at this location.

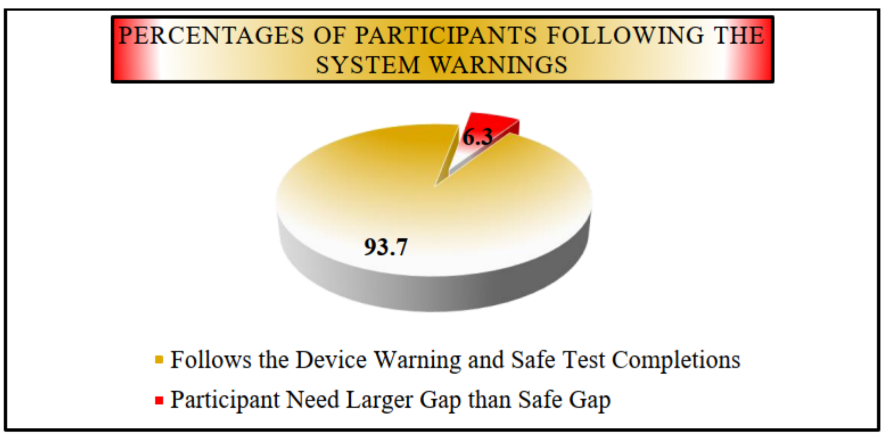

Figure VI.7 - Participants Closely Following the Warning Message

VII. CONCLUSION AND FUTURE WORK

Due to declines in the sensory and cognitive capacities and motor skill reductions, roadway entry requiring gap selection has become increasingly difficult for older drivers. The study proposed to develop and test a safety advisory system to help old drivers in gap selection at unsignalized T intersections. The design of the advisory system includes hardware installation, algorithm, and system calculations. Despite the fast-evolving CAV technologies, it is envisioned that the state of mixed traffic (CAVs mixed with regular human-driven vehicles) will last for a significant period of time. Thus, the proposed safety advisory system has taken into consideration two types of system design to handle CAVs (controlled situation) and the regular vehicles (uncontrolled situation) separately. In addition, this research has also tested different types of warning messages and identified from the limited testing the most preferred type of message presentation method to older drivers. Overall, the test results showed that the advisory system is effective in helping older drivers avoid unsafe gaps and improving potential conflicts with major road vehicles without affecting traffic operations.

Specifically, this research through field data studies estimated the critical gap at two test sites. The findings corroborate with the FHWA recommendation of using a longer gap for older drivers; in the meantime, it showed that different estimations should be made using local data to obtain the critical gap. The corresponding gap size at the field test site was adopted as the safe gap in the advisory system to support decision about warning message applications.

The simulation work investigating impeded speed as well as other MOEs found no significant changes in the average delay, average stopped delay and average queue length at low to medium level traffic volumes on the minor and major roads. Although those MOEs increase significantly at high traffic volumes on the minor and major roads, for traffic safety on behalf of older drivers, it is recommended that traffic signals be installed at such intersections if the high traffic volumes are sustained. The local traffic management agencies would very likely conduct a signal warrant study at those intersections with high traffic volumes.

The statistical testing on the field data after the installation of the warning system showed that an overwhelming majority of the participants consider the advisory system helpful and helping to improve traffic safety. Additional tests also mostly suggested that no significant difference exists when different factors, such as genders, type of system control, turning left or right, are considered as potential biases to the participants' acceptance of the system.

Lastly, the research found that a combination of red flashing with beeping as a preferred way to deliver in-vehicle warning messages to the older drivers.

In future studies, the advisory system may be further tested at other unsignalized intersections with different traffic volume characteristics. The in-vehicle red flashing display and the beeping sound can be further evaluated over its screen size, flashing intensity, and the sound of beeping. The data communication system can also be expanded to handle a large quantity of data exchange and command executions.

VIII. OUTPUTS, OUTCOMES, AND IMPACTS

A. Outputs

Presentations resulting from this study are listed below:

- Presentation. Development and Testing of a Safety Advisory System for Older Drivers at T-Intersections. COTA International Seminar on Traffic Safety, Beijing University of Technology, June 2023. Presenters: Dr. Ping Yi, Nader Elgehawe.
- Presentation. Development of a Prototype Safety Advisory System to Aid Older Drivers in Gap Selection. CCAT 2021 Global Symposium. Ann Arbor, Michigan, April 2021. Presenter: Dr. Ping Yi.
- Presentation. Understanding Gap Selections by Older Drivers at High-Speed Intersections. UA-Goodyear Research Collaboration Workshop. Akron, Ohio, September 2020. Presenter: Dr. Ping Yi.

B. Outcomes

The research project has successfully developed and tested an advisory system to enhance the safety and performance of older drivers at unsignalized T intersections. Through rigorous simulations and field tests, the system demonstrated its effectiveness in improving safety, minimizing impeded speeds, and providing tailored warnings for older drivers. The findings underscore the system's potential to significantly enhance intersection safety and traffic operations.

C. Impacts

The research project has yielded impactful outcomes with potential implications for intersection safety and traffic operations. By developing and testing an innovative advisory system for older drivers, the project contributes to enhancing their safety and reducing risks associated with merging into the major road from a minor road at unsignalized T intersections. The system's successful implementation has the potential to improve overall road safety, particularly for vulnerable road users, and enhance the efficiency of traffic flow at intersections.

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APPENDIX

Performance Indicators

Part I: UTC Program -- Project-Wide Performance Indicators

UTC Name: Center for Connected and Automated Transportation (CCAT)
University: University of Michigan/University of Akron
Grant #: 69A3551747105

OSTR Goals

METRIC	Research Performance Measures	University of Akron
1. Number of transportation-related courses offered during the reporting period that were taught by faculty and/or teaching assistants who are associated with the UTC.	Undergraduate courses	
	Graduate courses	1
2. Number of students participating in transportation research projects during the reporting period funded by this grant.	Undergraduate students in research	4
	Graduate students in research	2
3. Number of transportation-related advanced degree programs that utilize grant funds during the reporting period to support graduate students.	Masters level programs	1
	Doctoral level programs.	1
4. Number of students supported by this grant during the reporting period.	Undergraduate degrees	4
	Masters degrees	1
	Doctoral degrees	1
5. Number of students supported by this grant who received degrees during the reporting period.	Undergraduate degrees	4
	Masters degrees	1
	Doctoral degrees	1
6. Number and total dollar value of research projects selected for funding during the reporting period using UTC grant funds (Federal and/or Recipient Share) that you consider to be applied research and advanced research.	Number of applied research projects	1
	Dollar value of applied research projects	$75,000
	Number of advanced research projects	
	Dollar value of advanced research projects	

2.B CCAT affiliated students holding leadership positions	Number of students	
Education and Workforce Development Goals		
1. **OUTPUTS**	**Research Performance Measures**	
1.A Number of Workforce Online learning modules created and developed toward the certification of completion training for the emerging CAT field technician	Number of learning modules	
1.B Development of Articulation agreements for C++ software programs and Applied Data Science program with partner institutions	Number of Articulation/Transfer Programs	
1.C Development of an active WCC Pre-Engineering Program in STEM disciplines leading to an AAS degree	Number of students completed Associates Degree for Pre-Engineering Science Transfer	
	Number of students completed Associates Degree for Engineering Technologist-Manufacturing Degree	
1.D Number of curriculum development and professional development activities for instructors in related CAT technologies	Number of Professional Dev. Activities in IT [CAT]	
	Number of participants	
1.E Number of K-12 Career pathways activities related to CAT career fields.	Number of K-12 Activities in CAT Career Areas	
	Number of participants	
Outreach Goals		
1. **OUTPUTS**	**Research Performance Measures**	
1.A Media stories referencing CCAT, CCAT research or other activities	Number of media stories	
1. B Newsletters, press releases, and website	Number of newsletters	
	Number of press releases	
	Number of website hits	
2. **OUTCOMES**	**Research Performance Measures**	
2.A Research Champions	Industry principals	
	Number of industries represented	1
	Government principals	
	Number of government agencies represented	
Collaboration Goals		
1. **OUTPUTS**	**Research Performance Measures**	
1. A Collaboration with other agencies	Number of agencies providing matching funds	
	Number of agencies participating in CCAT events	
	Number of agencies committed to CCAT projects	
	Number of individuals from external agencies attending CCAT events	
1. B Collaboration with other organizations	Number of organizations providing matching funds	
	Number of organizations participating in CCAT events	3
	Number of organizations committed to CCAT Projects	3
	Number of individuals from external organizations attending CCAT events	

Part II: CCAT UTC -- Project Specific Performance Indicators

UTC Name: Center for Connected and Automated Transportation (CCAT)
University: University of Michigan/University of Akron
Grant #: 69A3551747105

Technology Transfer Goals

1. OUTPUTS	Research Performance Measures	University of Akron
1.A. Disseminate research results through publications, conference papers, and policy papers	Technical reports	1
	Papers at conferences, symposia, workshops, and meetings	3
	Peer-reviewed journal articles	
1.B. Develop inventions, new methodologies, or products	Annual number of research deployments	
1.C. Research projects funded by sources other than UTC and matching fund sources	Number of projects	
	Dollar amount of projects	
2. OUTCOMES	**Research Performance Measures**	
2.A. Incorporate new technologies, techniques or practices	Number of technology transfer activities that offer implementation or deployment guidance	
2.B. Improve the processes, technologies, techniques in addressing transportation issues	Number of research deliverables disseminated from each research project	1
3. IMPACTS	**Research Performance Measures**	
3.A. Increase the body of knowledge and safety of the transportation system	Number of instances of technology adoption or commercialization	
	Number of conferences organized by the CCAT consortium members	
3.B. Improve the operation and safety of the transportation system	Number of instances of research changing behavior, practices, decision making, policies (including regulatory policies), or social actions	1

Leadership Development Goals

1. OUTPUTS	Research Performance Measures	
1.A Keynote speeches or invited speaker presentations	Number of media engagements	
	Number of academic engagements	2
	Number of industry engagements	
2. OUTCOMES	**Research Performance Measures**	
2.A Leadership positions held	Regional organizations	
	National organizations	
	International organizations	