Effect of Inclement Weather on the Timing of the Change Interval

by

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Abstract

Research shows that there should be a longer change interval in inclement weather. However, there is limited knowledge on creating a longer change interval. This capstone report aims to provide insight into vehicles' speed and deceleration rates during inclement weather and recommend future studies. A radar gun was used to capture data on vehicles to understand how vehicle speed and deceleration rates differ in inclement weather. These data were captured on the southbound approach of the intersection of STH 100 (N. Mayfair Road) and W. Wisconsin Avenue in Wauwatosa, Wisconsin. Since there was a lack of inclement weather during the data collection of this capstone report, there was a limited amount of data. From the data that were collected, it can be concluded that vehicles drive slower than the posted speed and decelerate at a significantly slower rate during inclement weather. Because of the limited amount of data and known errors in capturing data, more research will need to be done before changes can be made to the timing of the change interval in inclement weather. Future studies utilizing the same concepts from this capstone report at a smaller intersection with more collection days could effectively prove the need for a longer change interval.

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Chapter One: An Understanding of the Change Interval

One of the most critical decisions a driver must make is the decision to stop or proceed through a traffic intersection upon the presence of the yellow light. The yellow, often referred to as amber light, is a duration of time in which drivers need to act fast and correctly or jeopardize the safety of all roadway users. This yellow light is also known as a change interval. It is associated with an equation to determine its length based on assumptions and known quantities. The equation's two default values are the driver's perception reaction time and deceleration rate. Weather also impacts the change interval and is currently not reflected in the change interval equation (Zhang et al., 2014).

This capstone report aims to provide insight into the change interval during inclement weather. The current change interval does not consider the effects of inclement weather and how drivers are more cautious, driving slower and decelerating at a slower rate. This report features several sections that address a number of topics that support this theory. First is the background information that explains the concepts behind the change interval and the equation. The second section is the literature review, which provides insight and direction for the experimental design. The third is the experimental design, where the data collection process is presented. The fourth is the field data analysis, and lastly, fifth is the conclusions and recommendations for future studies based on the results of the experimental analysis.

1.1 Background

There are three main topics that need to be addressed to properly understand the change interval. The three main topics are as follows:

- A high-level understanding of traffic signals

- What the change interval is and each associated variable
- The dilemma zone and the relationship it has to the change interval

Once there is an understanding of the change interval equation's basic ideas, the results of a literature review are presented on the current research trends to understand which aspects of the change interval equation inclement weather can affect. In addition, this report explains how the literature was used to create an experimental design with the purpose of demonstrating the effects of inclement weather.

1.1.1 Traffic Signals

Traffic signals are installed at an intersection of two or more roadways where a high amount of vehicle or pedestrian traffic occurs (Roess et al., 2019). When a traffic signal is present at an intersection, it is considered a signalized intersection; when there is no traffic signal present, it is an unsignalized intersection. A signalized intersection has a traffic signal, and on the traffic signal, there are three lights and four different intervals that give the driver instructions when crossing the intersection. When the traffic signal displays a green light, the driver is permitted to enter the intersection. When the traffic signal displays a red light, the driver cannot drive through the intersection. The green interval and red interval lengths are relatively straightforward to determine for a given intersection. When the traffic signal changes from displaying a green light to a red light, a yellow light gives the drivers time to react to the red. This yellow light is known as the change interval. The Institute of Transportation Engineers (ITE) describes the change interval in Roess et al. (2019) as follows:

> This interval allows a vehicle that is one safe stopping distance away from the STOP line when the GREEN is withdrawn to continue at the approach speed and enter the intersection legally on *yellow*. ‘Entering the intersection’ is interpreted to be front wheels crossing over the intersection curb line. (p. 419)

Lastly, an all-red clearance interval is determined through an ITE, created equation. This equation utilizes vehicle speed, the width of the road, including the crosswalk being crossed, and the standard length of a vehicle. The all-red clearance interval ranges from 1 second to 3 seconds and displays a red light for all approaches at an intersection. The all-red clearance clears the intersection from those still lingering after the change interval. While the all-red interval is not a requirement in every state, the ITE recommends using one immediately following the change interval for safety purposes (Roess et al., 2019). A set of equations can calculate each of the four different intervals seen on a traffic light. When the duration of each interval is obtained, a timing plan is produced for each intersection, showing what approaches will time concurrently and how long each interval will last.

1.1.2 The Change Interval

The change and the clearance interval are the first two values determined when determining traffic signal timing. Roess et al. (2019, p. 419) state, “Despite not being intuitive, the timing process starts with the determination of the yellow (change) and all-red (clearance) interval.” While a change interval is mandatory in all states, there are two legal meanings. A permissive yellow law indicates that the driver can enter the intersection during any point of the change interval. There is also a restrictive yellow law, which means that a driver must be entirely out of the traffic intersection by the end of the yellow or may not enter the traffic intersection unless it is impossible or unsafe to stop (Roess et al., 2019). Having multiple laws surrounding the change interval makes creating a universal equation to determine the duration of the change interval difficult, especially when the duration of the change and all-red intervals are vital to an intersection's successful and safe nature.

Determining the appropriate duration for the change interval is important for the safety of the intersection. ITE gives the recommended change interval equation in Roess et al. (2019, p 420) as

$$y = t + \frac{1.47S_{85}}{2(a+32.2G)}, \tag{1}$$

where

y = length of the yellow interval (second),

t = perception reaction time (second),

S_{85} = 85th percentile speed of approaching vehicles or speed limit (mile/hour),

a = deceleration rate of vehicles (ft/s^2),

G = approach grade (decimal).

ITE recommends in Roess et al. (2019, p 420) that in Equation (1), the standard default value for the deceleration rate for a vehicle is 10 ft/s^2, and the standard default value for perception reaction time (PRT) is 1 second. In Zhang et al. (2014), the definition of PRT is given: "PRT is defined as the time elapsed from the commencement of a yellow light until the vehicle brake light is illuminated" (p. 345). The deceleration rate is the rate at which a driver slows down at the sight of the change interval. Unless explicitly stated, these two standard default values are to be used in all situations. The approach grade and 85th percentile speed in Equation (1) are changing values specific to the intersection's geometry and traveling speed. While ITE suggests using this equation to determine the duration of the change interval, it is not mandatory. Traffic engineers might instead utilize knowledge of the intersection or past timing to determine the change interval duration instead of the change interval equation (Roess et al., 2019).

1.1.3 Dilemma Zone

One of the main reasons behind the need for the change interval equation is to eliminate the dilemma zone. Roess et al. (2019, p. 421) state, "The use of these ITE policies to determine yellow and all-red intervals assures that drivers will not be presented with a 'dilemma zone,' […]." Drivers approaching an intersection face a multitude of different situations. How the driver then responds to the situations will ultimately affect the safety of the driver and those surrounding them. The topic of the dilemma zone breaks down the decision that drivers will make when a traffic signal turns from displaying a green light to yellow light. Many different aspects determine how a driver will react in a dilemma zone, affecting intersection and driver safety. Gazis et al. (1960) were the first to coin the term *dilemma zone*:

> […] a car at a distance from the intersection smaller than x_o cannot stop safely, whereas a car at a distance greater than x_o cannot go through the intersection without accelerating before the light turns red. As mentioned already, when $x_o<x<x_c$, which in the sequel will be referred to as the 'dilemma zone.' (p 121)

Gazis et al. (1960) show in Figure 1 the meaning of the dilemma zone.

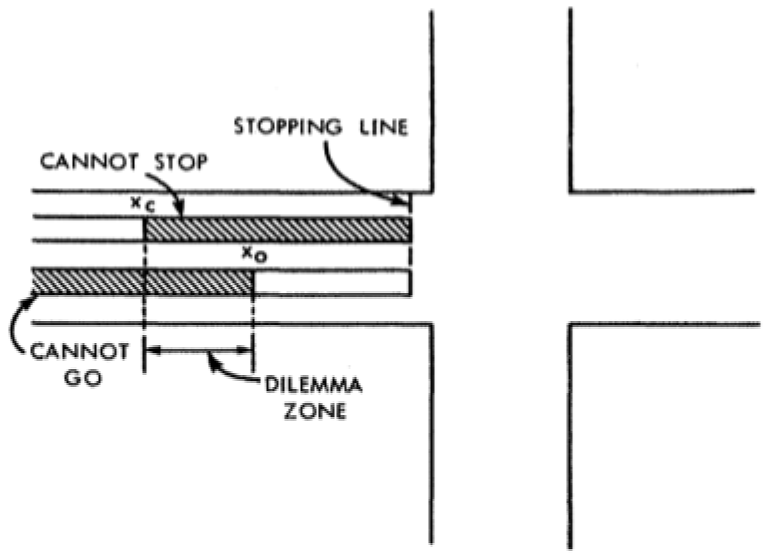

Figure 1: Schematic Diagram Showing the 'Dilemma Zone' (Gazis et al., 1960).

Every time a driver nears an intersection, a decision has to be made. The complexity of that decision is exacerbated when a driver is inside the dilemma zone and, depending on how they make that decision, it could be dangerous. The driver can proceed through the intersection and run the risk of running a red light and/or getting into a right-angle crash. Or the driver may stop and have a greater chance of a rear-end collision from applying the brakes suddenly. The decision to go or to stop within the dilemma zone is difficult to model and understand. The most significant decision stems from human behavior. Along with human behavior, deceleration, PRT, and different weather/pavement conditions can also be associated with the dilemma zone and how drivers make their decisions.

Chapter Two: Literature Review

A literature review was completed on relevant literature in three different areas surrounding the change interval equation. The first two areas are the default values in deceleration rate and PRT and how effective the default values are for the equation. The last area is the impact of weather on the change interval and the lack of weather-related assumptions built into the equation. The research was compiled through articles, case studies, and other resources that were found in the Milwaukee School of Engineering [MSOE] library databases using relevant terms. The relevant terms utilized to aid in compiling research were *yellow interval*, *change interval*, *yellow light running*, *traffic signals*, *signalized intersections*, *driver safety*, *perception reaction time*, *weather effects*, and *deceleration rate*.

The following sections employ literature to understand what research has been conducted on the three aspects of the change interval equation. Different studies involving the PRT value, the deceleration rate, and the impact of weather are discussed with respect to the effectiveness of the change interval equation.

2.1 Perception Reaction Time

Questions on the adequacy of having a 1 second PRT have been discussed for many years. It is essential to understand how long the PRT default value should be, as having it wrong would significantly affect the safety of the drivers. Having an incorrect PRT can impact the dilemma zone, the number of accidents, and overall traffic movement. Drivers with different ages, the roadway geometry, and the duration of the change interval can impact a driver’s PRT (Caird et al., 2007; Wong & Goh, 2000).

A study reported in “The Effect of Yellow Light Onset Time on Older and Younger Drivers Perception Reaction Time (PRT) and Intersection Behavior” (Caird et al., 2007) created a driving simulation that considered different aged drivers and how their perception reaction time would vary in different durations of change intervals. Then the comparison to other studies regarding perception reaction time were compiled into Table 1. During the study, it was found that age did play a small role in how successfully and quickly a driver would stop when shown the change interval. The factor that affected the PRT the most was the duration drivers had to react. The study showed that if a driver had more time to react through a more extended change interval duration, the driver would take more time to react. Aside from one of the groups in the study that had the most prolonged change interval duration, 90 percent of all the drivers had a PRT value of 1.01 seconds. Each of the different studies showcased in Table 1 effectively indicates that the median PRT value is between 0.9 to 1.1 seconds. Therefore, it could be concluded that a PRT of 1 second would be sufficient for the change interval equation.

Table 1: Summary of Yellow Light PRT Studies (Caird et at., 2007).

Study (date) (ref. #)	Study type	Intersection, driver characteristics	Mean PRT (SD)	Range	Median	85th Percentile
Gazis et al. (1960)	Observational, analytic	Three intersections, Speed limit 40–45 mph, $N = 87$	1.14 (0.28)	0.6–2.4	1.1	1.5
Crawford (1962)	Experimental, test track	three vehicles, six men, two women, 20–60 mph, $N = 650$ stops		0.8–1.85		
Wortman and Matthias (1983)	Observational, field	Six intersections, $N = 839$, Speed limit 30–50 mph	1.3 (0.6)	1.09–1.55[a]		1.8
Chang et al. (1985)	Observational, field	13 intersections, $N = 579$, speed limit 30–55 mph	1.30.9[b]	0.7–1.55	1.1, 0.9[b]	1.9, 2.5, 95th
Mussa et al. (1996)	Experimental, driving simulator	$N = 41$, ages 18–58, 40.3 and 72.5 km/h approach speeds	1.16			
Knoblauch et al. (1995)	Experimental, test track	$N = 81$, 40 men, 41 women, 20 and 30 mph approach speeds, 3.5 and 4.5 TSL	0.59–0.78[c]			0.74–1.26[c]
This study.	Experimental, driving simulator	$N = 77$, 18–24, 25–35, 55–64, 65+, 70 km/h limit	0.96 (0.27)	0.5–2.2	0.92	1.22, 1.45, 95th

Notes:
[a] Range of mean times across intersections and conditions observed.
[b] Value for vehicle approaches over 40 mph.
[c] Range of mean times over middle-aged and older drivers, approach speeds (20, 30 mph) and time from signal (~3.5 and 4.5 s).

A second study reported in “Drivers Perception Response Time During the Signal Change Interval” (Wong & Goh, 2000) was performed with various ages, with different geometric roadway properties, and with enforcement risks. The study noted that PRT did not change based on geometry and collision risks presented at the different test intersections. The 85th percentile PRT was determined to be 1.0 to 1.13 seconds, aligning with the default perception reaction time.

2.2 Deceleration Rate

The deceleration rate plays a prominent role in Equation (1). ITE determined that the default value for the deceleration rate is 10 ft/s^2. The American Association of State Highway and Transportation Officials (AASHTO) recommends a deceleration rate of 12.9 ft/s^2 (Zhang et al., 2014). Deceleration rates vary by driver’s age, the distance inside the dilemma zone, and the duration of the change interval. The deceleration rate also has an extensive variance due to different circumstances (Caird et al., 2007; Gates et al., 2007).

A study was conducted in “The Effect of Yellow Light Onset Time on Older and Younger Drivers Perception Reaction Time (PRT) and Intersection Behavior” (Caird et al., 2007) to determine the mean rate of deceleration. The two different characteristics that affected the deceleration rate were the distance to the stop line and the driver’s age. The mean deceleration rates ranged from 8.2 ft/s^2 to 18 ft/s^2. The higher deceleration rate was associated with younger drivers, and older drivers recorded lower deceleration rates. Also, the study determined that the longer the change interval, the more time the driver had, and the slower the deceleration rate recorded.

Another study conducted in “Analysis of Driver Behavior in Dilemma Zones at Signalized Intersections” (Gates et al., 2007) showed a range of deceleration rates from 7.2 ft/s^2 to 12.9 ft/s^2 for vehicles that were in the estimated dilemma zone at the start of the change interval. This study noted that vehicles would be more likely to run through an intersection if there is an extended change interval and a shorter travel distance to the intersection. They also noted that larger vehicles such as dump trucks, semi-trucks, and buses would be less likely to decelerate when shown the change interval and proceed through the intersection. In both studies, different parameters were utilized to determine the mean deceleration rate. Another way deceleration rates can vary is during inclement weather and the everchanging pavement conditions.

2.3 Weather Impacts

The weather has an enormous impact on many different aspects of the roadway, such as safety, mobility, and efficiency (Pisano & Goodwin, 2002). Table 2 shows the various weather events and their effect on the roadway and traffic operation. In inclement weather such as rain or snow, visibility and traction will decrease, affecting speed, perception reaction time, and deceleration. That will, in turn, affect the safety and efficiency of the roadway and intersections (Pisano & Goodwin, 2002). Equation (1) assumes dry pavement conditions and clear visibility when determining the duration of the change interval (Roess et al., 2019). When using a change interval duration that is meant for dry pavement, traffic signals and timing are ineffective in inclement weather conditions. When in inclement weather, the dilemma zone becomes a greater distance for drivers. The dilemma zone becomes an issue due to the decreased lack of traction on the pavement, forcing drivers to reduce speeds and to be more cautious when accelerating and decelerating. Therefore, more time is needed to help in eliminating the dilemma zone in inclement weather. Overall, drivers will take more time to accelerate and decelerate, and their PRT will be affected by decreased visibility and an increase in distractions on the road (Perrin et al., 2001). The literature primarily recognizes the roadway impacts, but does not adequately address the effects on signal timing. Only two different studies explicitly discuss the impact weather has on signal timing.

Table 2: Weather Impacts on Roadways and Traffic Operations (Pisano & Goodwin, 2002).

Weather Events	Roadway Impacts	Traffic Operation Impacts
Rain, Snow, Sleet, Hail & Flooding	• Reduced visibility • Reduced pavement friction • Lane obstruction & submersion • Reduced vehicle performance • Infrastructure damage	• Reduced roadway capacity • Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures
High Winds	• Reduced visibility due to blowing snow/dust • Lane obstruction due to wind-blown debris & drifting snow • Reduced vehicle performance	• Increased delay • Reduced traffic speeds • Road/bridge restrictions & closures
Fog, Smog, & Smoke	• Reduced visibility	• Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures
Lightning & Extreme Temperatures	• Infrastructure damage	• Traffic control device failure • Loss of power/communications services

In “Modifying Signal Timing During Inclement Weather” (Perrin et al., 2001), a study was completed in Utah to determine the factors that change when timing traffic signals during inclement weather. In the study, the saturation flow rate decreased by 20 percent, the speeds were reduced by 30 percent, and start-up lost time increased by 23 percent from the dry condition study. Drivers reduced speeds, taking longer to accelerate or decelerate, affecting the saturation flow rate. Saturation flow rate is the maximum number of vehicles for a single lane under ideal conditions that can cross an intersection, assuming 100 percent green time. Therefore, fewer vehicles can proceed through the intersection during the green interval with a decreasing saturation flow rate. It was found that saturation flow decreases as the severity of a storm increases. The start-up lost time is the time lost when starting the green interval for vehicles to react to the changing of intervals and to accelerate. It was found that the increased start-up lost time was due to the lack of tire traction and the desire to have more room in between vehicles in wet pavement conditions than in dry conditions. Given this amount of information, it was determined that the change interval should increase by 10 to 15 percent or an additional 0.5 seconds to 1 second. Also, the study showed that change interval durations should have a more significant increase when in high speed or high-grade approaches.

In “Weather and Traffic Analysis, Modeling and Simulation” (Park et al., 2010), “Benefit Assessment of Implementing Weather-Specific Signal Timing Plans by Using CORSIM” (Lieu & Lin, 2004) and “Inclement Weather and Traffic Flow at Signalized Intersections: Case Study from Northern New England” (Agbolosu-Amison et al., 2004), the researchers all performed modeling simulations that take into account weather effects. There was no specific conclusion developed in these studies on how the change interval duration should be impacted. Each of the studies concluded only that there should be a signal timing plan for inclement weather to give drivers more time. The studies found that if a different timing plan is utilized in inclement weather, the better the traffic would flow, thus increasing the saturation flow rate.

2.4 Summary

The literature reviewed provides insight into the different research trends pertaining to the change interval and its equation. It shows that more research has been done on the concept of the change interval than on the equation itself. The literature also indicates the need to better understand driver behavior and how it affects PRT and deceleration rate. There was also an overall lack of research surrounding inclement weather and how the change interval equation itself should be modified to account for these conditions.

Research reported in all literature consulted supports the idea that a small range around 1 second should be employed for a PRT value. Drivers’ PRT varies depending on how far away the vehicle is from the stop line and how long the change interval lasts. Drivers that needed to react quickly while inside the dilemma zone were able to do so in less than 1 second. Those outside the dilemma zone could use more time to react, ranging closer to 1.5 seconds. The studies that utilized age and gender found there was no substantial evidence to indicate age or gender played a role in reaction time. Lastly, the PRT time should not change with roadway geometry because there was no evidence to conclude that it had an impact (Zhang et al., 2014; Wong & Goh, 2000; Caird et al., 2007). Also, the standard deviation, mean, and the 85th percentile were used interchangeably in the literature regarding PRT. Table 1 shows there is a significant range between age and gender in each of the studies. What should be considered when determining the default value for PRT in the change interval equation? Is it the standard deviation, mean, or the 85^{th} percentile time? This lack of consistency equates to about one-half of a second, which can be a significant amount of time. Therefore, it is valid to question which variable or variables should be used in determining the proper duration for the change interval. There is a lack of consistency in the PRT studies, and that lack of consistency is also displayed in the deceleration studies.

Research shows considerable variance in the appropriate deceleration range. While one study concluded that age and gender did not play a role (Hass et al., 2004), two other studies concluded that they did (Caird et al., 2007; Gates et al., 2007). While differing opinions are evident with respect to the different conditions that can affect deceleration, an extensive range is associated with the overall deceleration rate. Every study features a different range, from the lowest rate at 7.2 ft/s^2 to the highest rate of 18 ft/s^2 (Caird et al., 2007). That is an extensive range with little information available in the literature in understanding why drivers—besides age and gender—had differing deceleration rates. Should the change interval equation have a default range of deceleration values? Each of the studies found it difficult to select one deceleration value even in a controlled environment. What happens to the deceleration rate in different situations or dilemma zones? Or different weather situations? The studies do not address a lot of variation in situations and how it can change the deceleration rate.

There is a lack of literature on the direct impact that weather may have on the timing of the change interval. There is also a knowledge gap regarding how the change interval equation can be modified to incorporate different weather conditions. The studies reveal the different performance measures that decrease in inclement weather, but there is a knowledge gap in the literature as researchers did not investigate how to directly modify the change interval equation to help improve the roadway's saturation flow rate. Each of the studies conclude only that there should be an increase in the change interval or a new signal timing plan during inclement weather, as many factors worsen in poor weather conditions. Understanding PRT and deceleration rates during inclement weather would be very beneficial in creating a new signal timing plan.

2.5 Conclusions

The literature presents an interesting perspective on three different aspects of the change interval equation. In almost every study, there is some form of indecisiveness with respect to understanding human behavior. There is much variability in the research for all three topics. There is a wide range of values regarding default values and the effect of inclement weather on these values. This state of affairs provided the motivation and the direction for this capstone paper. While the default value for PRT of 1 second was deemed relatively accurate in the research, the variance in which statistical measure is appropriate is a concern. The lack of understanding regarding the deceleration rate is another concern, as an extensive range of values are reported. To account for most drivers, a range of default values for the deceleration rate could potentially be better for the effectiveness of the change interval and the saturation flow rate. However, a knowledge gap exists regarding how weather impacts the change interval. While the effect of weather is acknowledged in the literature, an effective timing plan for inclement weather conditions can only be obtained and considered with additional research.

Chapter Three: Experimental Design Method

Based on the literature discussed in Chapter Two, there is a need to understand the current knowledge gap regarding the change interval during inclement weather conditions. The hypothesis and experimental design, for this capstone project were designed to investigate how variables in the change interval equation should differ in inclement weather.

3.1 Background

Reviewing the variables in Equation (1), there are two variables for which literature indicates the need for additional data, especially during inclement weather conditions. Those variables are the 85th percentile speed of drivers and drivers' deceleration rate. In the literature regarding the impacts of inclement weather on the change interval, it is noted that there will be a decrease in overall speed and deceleration rate due to visibility and traction (Perrin et al., 2001). While a 10 ft/s2 default value for deceleration rate is currently utilized in the equation, the literature features differing opinions—thus providing the need to gather more information (Caird et al., 2007; Gates et al., 2007; Hass et al., 2004). It can be assumed from the literature that a 1 second PRT is acceptable for all ages and genders (Zhang et al., 2014; Wong & Goh, 2000; Caird et al., 2007). With the slight variability in the various literature studies, a 1 second PRT is acceptable even in inclement weather. The last variable is the grade of the intersection, and to be able to eliminate this term from Equation (1), the intersection that was investigated in this capstone project features a grade of zero. More information is needed to determine a new change interval equation; in this capstone project, a hypothesis for the

85th percentile speed and the deceleration rate in inclement weather were employed to lead the experiment.

3.2 Hypothesis

A hypothesis was generated to guide the experimental design to ensure field data could be accurately collected and placed into the change interval equation. An understanding of the different variables found in the change interval equation and how they differ in inclement weather was determined through data collection. The hypothesis for this experimental design was that when it is snowing, both the 85th percentile speed and the deceleration rate of vehicles will decrease due to poor pavement conditions and visibility.

3.3 Experimental Design

A collection of speeds and deceleration rates at a given intersection during inclement weather were employed to investigate the hypothesis. The intersection and experimental procedure needed to remain consistent throughout the experiment. With the intersection and experimental procedure remaining constant, vehicles' speed and deceleration rates could be determined during inclement weather.

3.3.1 Background

The ideal intersection for the experimental design needs to experience significant traffic volume. The intersection also needs to feature zero grade change on the approach so that traffic could be observed. Finally, the majority of the traffic volume on the observed approach needed to proceed through the intersection. Given these three criteria, the intersection of State Trunk Highway (STH) 100 (N. Mayfair Road) and W. Wisconsin

Avenue in Wauwatosa, Wisconsin, was selected to perform the experiment. Figure 2 displays the intersection of STH 100 (N. Mayfair Road) and Wisconsin Avenue. As shown in Figure 2, STH 100 (N. Mayfair Road) has the greater capacity with four through lanes, while W. Wisconsin Avenue has two lanes. The southbound approach on STH 100 (N. Mayfair Road) was chosen for the experiment as the approach is flat and volumes proceed through the intersection.

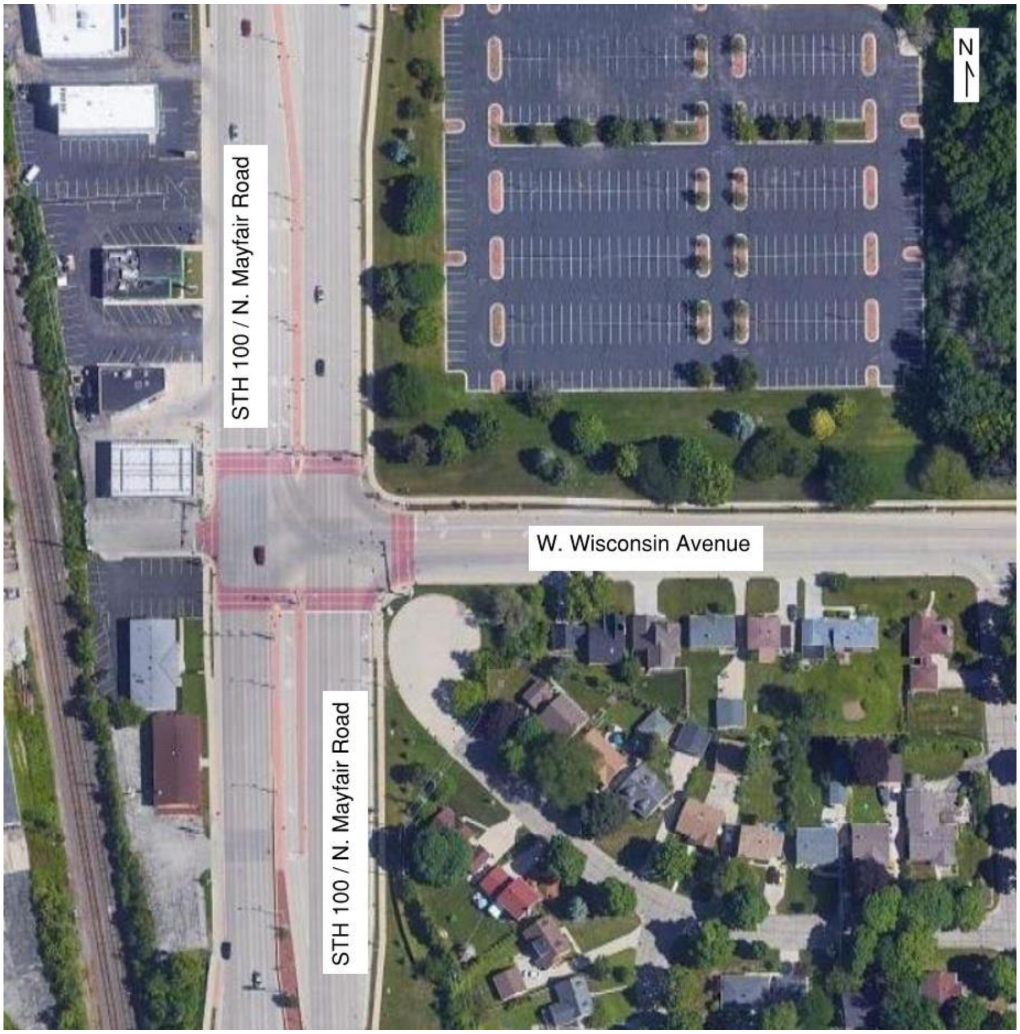

Figure 2: STH 100 (N. Mayfair Road) and W. Wisconsin Avenue Intersection (Google, n.d.).

The intersection is operated and maintained by the Wisconsin Department of Transportation (WisDOT); therefore, WisDOT provided information for the intersection. The information assisted with understanding the current intersection operation. WisDOT provided manual turn counts, traffic signal timing, crash data, and the plan and profile for the intersection. These four documents are included in Appendix 1.

STH 100 (N. Mayfair Road) has a design speed of 40 miles per hour (mph), and the intersection utilizes an adaptive traffic signal control system. An adaptive traffic signal control system is a control system that regulates the green time based on current traffic conditions (Roess et al., 2019). The clearance and the change interval timing remain consistent, but the red and green intervals will change based on traffic volumes. The change interval for this intersection is programmed at 4.0 seconds. The intersection's most current manual turn count data were collected on Thursday, March 12th, 2020. From these data, the Annual Average Daily Traffic (AADT) of the intersection is 40,224 vehicles, and the AADT of the southbound approach is 17,848 vehicles. The intersection experiences minimal pedestrian usage. Lastly, the crash data from the three most recent years were reviewed to identify possible crash trends. From 2018 to 2020, there was an average of 4.67 crashes per year, with a crash rate of 0.32 crashes per million vehicles entering. WisDOT in "Statewide Average Crash Rates and Upper Control Limits" (Brugman, 2021) states no specific threshold crash rate for assessing intersection safety issues. Therefore, since there is no ability for comparison, it was assumed there was not a crash concern at the intersection. Reviewing the crash data, there were no crash trends related to the change interval timing, but there were two crashes where wet pavement was noted in the crash report.

3.3.2 Experimental Tools

A speed radar detector was needed to accurately gather vehicle speeds and deceleration rates for the experiment. From Pocket Radar Inc. (n.d.), The Traffic Advisor Radar™ Model PR1000-TA was utilized to collect the intersection data necessary to investigate the hypothesis. Figure 3 from Pocket Radar Inc. (n.d.) is a picture of the Model PR1000-TA.

Figure 3: Model PR1000-TA Traffic Advisor Radar (Pocket Radar Inc., n.d.)

Traffic engineering professionals use this model for certified speed studies and for gathering vehicle speeds. The product description for the Pocket Radar Inc (n.d.), Model PR1000-TA is:

> The professional grade Traffic Advisor Radar™ is the state of the art in advanced handheld radar technology. The Traffic Advisor Radar™ is the world's smallest certified accurate speed radar. Designed for traffic professionals and engineers that require independent certificates of accuracy by the police radar test lab. Accurate to within +/- 1 mph (+/- 2 kph), has a ½ mile range on a car and measures from 7 mph to 325 mph. (para. 1)

This paper refers to the Traffic Advisor Radar™ Model PR1000-TA as the speed radar. The radar measures an object moving in line with the radar beam, so the vehicle must be within the radar beam cone. This means that the speed radar is the most accurate when standing as close to inline with oncoming traffic and this requirement impacts how to gather data at the intersection.

3.3.3 Speed

Data gathering consistency is critical in forming valid recommendations on the change interval variables in inclement weather. First, in this capstone project, it was determined where the person collecting data would stand to ensure the speeds measured would be at operation speed, not deceleration speed. After observing the intersection, the best location to collect data was determined to be 430 feet from the southbound stop bar. The location and dimensions are shown in Figure 4. The red circle indicates the location of the speed radar where speeds were collected. The person collecting vehicle speeds was standing as close as possible to inline with the traffic to ensure the accuracy of the speed radar.

Figure 4: Radar Location for Gathering Speeds at STH 100 (N. Mayfair Road) and W. Wisconsin Avenue Intersection (Google, n.d.).

When recording vehicle speeds, not every vehicle should be measured. Only the first vehicle should be taken if there is a platoon of vehicles—a platoon forms when a group of vehicles travels along a signalized roadway, proceeding in a manner that allows them to move through several signals continuously. During platooning, only the first driver chooses the speed, and the rest of the vehicles in the platoon follow that set speed (Roess et al., 2019). If the speed of every vehicle in the platoon was collected, data would be skewed. Also, vehicles that turned onto STH 100 (N. Mayfair Road) from an adjacent intersection and turning at the intersection were not measured as they were likely not at full operating speed. Lastly, since the speed radar is most accurate when facing the vehicle head-on, vehicles from the nearest lane or the right lane were the only vehicles recorded. Given these potential sources of error, the vehicles' speeds driving on STH 100 (N. Mayfair Road) were accurately gathered.

3.3.4 Deceleration Rate

Assumptions were made to utilize the speed radar while determining the deceleration rate. The speed radar detects the speed of vehicles, not their deceleration rate. Equation (2) from Evans (2011, p. 9) was utilized to determine the deceleration rate of vehicles. Thus:

$$a = \frac{v_i^2 - v_f^2}{2x}, \qquad (2)$$

where

a = deceleration rate of vehicles (ft/s^2),

v_i = initial velocity (mph),

v_f = final velocity (mph),

x = distance traveled.

It was assumed that every vehicle would be at zero mph at the stop bar and that all the vehicles were decelerating at a consistent rate. The final assumption was that all vehicles had already started decelerating at the location where the data were being collected. In order to determine the location where vehicles began decelerating, an observation of the intersection was performed. This observation determined that all vehicles were decelerating at a point 230 feet from the southbound stop bar, which is where the speed radar was then located, and a red circle in Figure 5 shows the location.

Figure 5: Radar Location for Gathering Deceleration Rate at STH 100 (N. Mayfair Road) and W. Wisconsin Avenue Intersection (Google, n.d.).

While at the location 230 feet from the stop bar, the speeds of the vehicles during the change interval were recorded. Vehicles recorded were during either the change interval or the start of the red interval as long as they were the first vehicle to the stop bar.

Only the first vehicle to decelerate and stop at the stop bar was recorded. The second car to stop was not traveling to the stop bar; therefore, the distance the vehicle was traveling is not 230 feet and would result in a wrong deceleration rate. Also, if vehicles are platooning, that can change a driver's desired deceleration rate. Therefore, the speeds collected were the first vehicle to stop at the stop bar in the right lane.

3.3.5 Recording Data

Inclement weather for this experiment was defined as at least 0.5 inches of snow accumulation to gather consistent data. Utilizing a snowfall of at least 0.5 inches would ensure that there would be a considerable amount of snowfall on the pavement, which would result in slicker conditions than would occur from a light dusting of snow. From the Midwestern Regional Climate Center (2014), winters in Milwaukee, Wisconsin, from 1981 to 2010, had on average 13.4 days of snowfall a year with more than 1 inch of snow. The station USW00014839 Milwaukee Mitchell Airport, where the data are gathered, is approximately 10 miles from the intersection, and similar weather patterns may be assumed in Wauwatosa. It was safe to assume there would be plenty of days with over an inch of snow to gather data. The more data points collected in similar inclement weather conditions, the more accurate the conclusions would be. Since not every snowstorm is identical, the differences in pavement condition and visibility were noted on the field's datasheet.

An additional person was utilized for the safety and accuracy of data collection. Benjamin Quintero (MSOE graduate student in civil engineering) assisted with field data collection and recording speed data gathered with the speed radar. Speeds were recorded using a datasheet produced in Excel. There were two different datasheets, one for speeds and one for deceleration. The upper half of each datasheet required the same information regarding the time, place, and weather conditions present at the intersection. The lower half of the datasheet was used to record vehicle speeds. More vehicle speeds can be recorded in the speed datasheet than in the deceleration datasheet. The deceleration datasheet required more information regarding traveling distance and ending speeds to calculate the deceleration rate. Figure 6 shows the deceleration datasheet, which, unlike the speed datasheet, has columns in the lower half to be able to calculate the deceleration rate. The speed datasheet has no columns in the lower half and just has places for the vehicle’s speeds to be placed. The average speed and deceleration rate were calculated at the very bottom of both datasets. These two datasheets were brought to the intersection and utilized in investigating the hypothesis.

Date		Inspector	
Temperature		Pavement Condition	
Snow Accumulation		Driver Visibility	
Intersection			
Location of Radar			
Notes			
Distance Traveled (ft)	Starting Speed (mph)	Ending Speed (mph)	Deceleration Rate (ft/s^2)
Average Deceleration Rate (ft/s2)			

Figure 6: Deceleration Datasheet Template.

Chapter 4: Field Data Analysis

What proved quite problematic throughout the winter months was, in fact, snow. The winter of 2021-2022 only featured 22 inches of snowfall in Wauwatosa, where an average winter has close to 50 inches of snowfall (National Weather Service, 2022). Collecting data was quite difficult with this little snowfall. One snowfall occurred during the day and satisfied the inclement weather conditions set out in the experimental design. The remaining snow was merely a dusting or occurred during the night hours. Rain events were considered in late winter/early spring as the occurrence of snowfall seemed bleak. However, the decision was made to continue with only snow events. Additional snowfalls did not happen, and as a result, there was one dataset collected and analyzed for this study.

4.1 Collected Data

The single data collection period was on January 24th, 2022. From the National Centers for Environmental Information [NCEI] (n.d.), there was a recorded 1.5 inches of snowfall 3.6 miles away from the intersection at station US1WIMW0046. Data were collected from 10:00 am to 11:00 am. Figure 7 shows the pavement conditions as data were being collected.

Figure 7: Pavement Conditions.

As seen in Figure 7, the pavement conditions were hazardous, and all the data were collected as the snow was falling and before plows cleared the roadway. Ninety-one operating speeds were recorded, with an average speed of 28.0 mph compared to the roadway's posted speed of 40 mph. The average vehicle speed was 30 percent lower than STH 100 (N. Mayfair Road)'s posted speed. Figure 8 shows Benjamin Quintero collecting data using the speed radar. Additionally, 21 vehicle speeds were collected to obtain the deceleration rate. With these speeds, the calculated deceleration rate was determined to be 2.0 ft/s^2, which is significantly less than the default value of 10 ft/s^2. The datasheets showing the gathered speeds and calculated deceleration rates are found in Appendix B.

Figure 8: Collecting Speeds.

Collecting the average vehicle speed proved to be the most straightforward data collection procedure. While obtaining the speeds through the speed radar was challenging, collecting and recording the data were fairly simple. Obtaining deceleration rates proved challenging as the change interval is shorter than the green time, and only the first vehicle to stop at the stop bar could be measured. While it proved more difficult, good readings were obtained to investigate the hypothesis.

Chapter Five: Conclusions and Recommendations

From the field data analysis in Chapter Four, it can be concluded that an extended change interval during inclement weather should be recommended. However, because there was a lack of a sufficient amount of collected data, future studies are recommended.

5.1 Conclusions

Even with the lack of data, a strong conclusion can be inferred that a more extended change interval equation is warranted for inclement weather. At the same time, the experiment was unable to pinpoint at which precise depth of snow the deceleration rate should fluctuate, or which speed should be used. Solely utilizing observation at the intersection, it can be seen that drivers are significantly more cautious. Drivers are not driving the same in inclement weather as in perfect conditions. Vehicles are being driven at lower speeds, leaving more space between vehicles, and gradually decelerating. Each of these observations can help support the idea of the need for a longer change interval. Utilizing Equation (1) with the perception reaction time of 1 second, the recorded speed of 28 mph, calculated deceleration rate of 2.0 ft/s^2, and grade of 0 ft/ft, the change interval should be 11.3 seconds. With the current change interval of the intersection at 4 seconds, programming to 11 seconds would be drastic, but the data collected do indicate more time. Since the change interval would be 2.75 times longer than currently programmed interval, more data would be needed before implementing this timing during inclement weather.

5.2 Sources for Error

Even with only one actual data gathering day, issues concerning the speed radar could be raised, which could in turn undermine the validity of the conclusion in this capstone project. The primary concern is that it was difficult to know which vehicle was being measured by the speed radar. The actual radar mechanism is located on the upper backside of the speed radar, and if it is facing vehicles that are moving, there is no way to understand which vehicle is being measured. Figure 9 shows the backside of the speed radar; the square at the top is the radar collecting the speed of objects in its view frame that are moving.

Figure 9: Backside of the Model PR1000-TA Traffic Advisor Radar (Pocket Radar Inc., n.d.)

Not knowing which vehicle was actually measured became a possible source of error when vehicles were in all four lanes of STH 100 (N. Mayfair Road), and each was at a different location. Without knowing which vehicle was recorded, the vehicle's location, and lane became unclear. Also, recording the vehicle's speed to calculate the deceleration rate accurately at a precise location rendered the potential for error in the calculated deceleration rate probable. Lastly, it was quite possible that while collecting speeds, one vehicle could have been read multiple times unknowingly. As speeds were obtained, the speed radar button had to be pushed; therefore, speeds were taken consecutively as vehicles passed from different lanes and spots, and one vehicle mistakenly could have been recorded twice.

While it would be hard to design an experiment in the field without any sources for error, utilizing a speed radar for this experiment was probably not the most effective procedure for maintaining consistency. Having more than one data set would have helped to ensure a more representative data sample. The speed radar would have worked perfectly in a location with only one lane or less consistent traffic. It can still be concluded solely by observation that drivers were driving at much slower speeds and using more caution when decelerating. Considering the possible introduction of statistical bias in this experiment, recommendations for future studies would include the need to choose an intersection that could better suit a speed radar.

5.3 Recommendations

Even with the lack of data, there is still strong observational data suggesting the need for a longer change interval time during inclement weather. In order for any change to be made on how timings are calculated and signal timing plans are implemented in the field, more research would need to be done. If there had been more time or one more year to collect data, these are the lessons learned from this experiment that would need to be implemented in a future study.

- Only collect vehicle speeds and not deceleration
- Utilize a smaller, one-lane roadway
- Gather data no matter the amount of snow
- Develop a change interval time for inclement weather
- Place the new change interval time for inclement weather
- Visualize the results of the new timing

From observations of the intersection, it can be seen that vehicles are driving significantly slower in inclement weather. Since there is so much variability in the deceleration rate, and larger studies could not obtain a reasonable range for drivers, it seems more realistic to focus on vehicle speeds. Placing a slower vehicle speed into the change interval equation will still produce a longer change interval that could be implemented and would be more realistic than what was found in this experiment. To eliminate some of the potential sources of errors found in this experiment, utilizing a smaller intersection would eliminate most of the sources of errors and remove the deceleration rate from the study. It is also hoped that by gathering data at all snow events, there would be more data, and different timings could be produced depending on how much snow is predicted to fall. How vehicles driving in varying levels of snowfall impacts the speed at which they travel could be clarified. Lastly, being able to calculate the change interval and, with enough time, implement it into the signal for a special signal timing plan would benefit the experiment. Visualizing and recording drivers' behavior with respect to a longer change interval is vital to being able to fully enact a longer change interval into practice during inclement weather. Suppose drivers react well to a longer change interval, and it helps to improve the intersection flow rate and safety. In that case, it could change how signal engineers determine interval timing at an intersection during inclement weather.

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Appendix A: STH 100 (N. Mayfair Road) and W. Wisconsin Avenue Reference Documents

STH 100 (N. Mayfair Road) and W. Wisconsin Avenue intersection reference documents. The reference documents from WisDOT are manual turn counts, traffic signal timing, crash data, and the plan.

Manual Turn Counts

Intersection Traffic Volume Report

Count Basics		Version 2011.M3	Page 1 of 13
Start Date:	Thursday, March 12, 2020	Weekday	Schools in Session
Total Number of Hours Counted: 13		Non-Holiday	No Special Events

Base Information, Observed (13) Hour and Estimated (24) Hour Volume Summaries

Intersection of: STH 100 & W Wisconsin Ave

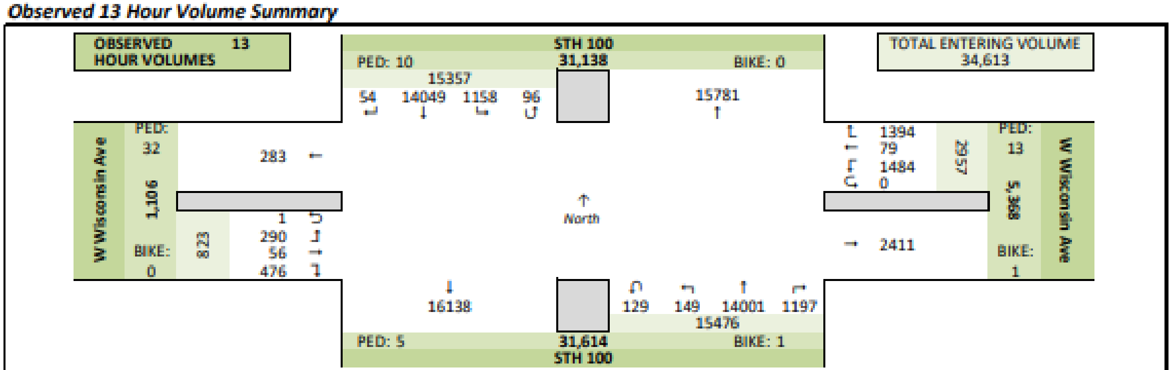
Site Information

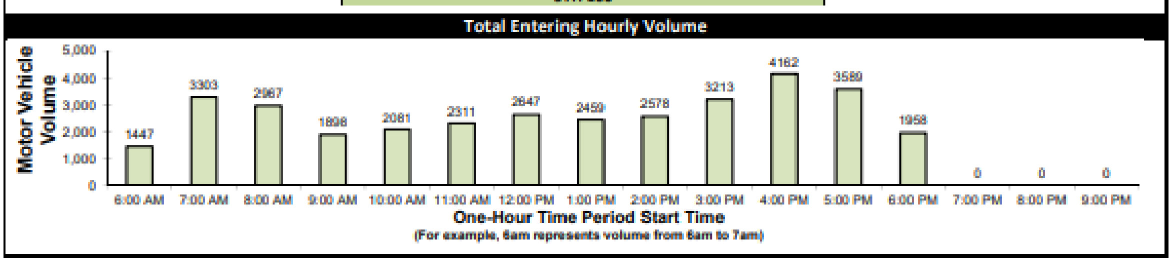
Municipality	City of Wauwatosa		
County	Milwaukee	WisDOT Region	SE
Traffic Control	Traffic Signal		
Roadway Names		North Direction	↑
North Leg	STH 100		
East Leg	W Wisconsin Ave		
South Leg	STH 100		
West Leg	W Wisconsin Ave		
Special Considerations			
Schools	In Session		
Holidays	None		
Special Events	None		
Special Pedestrians Observed			
Pre-school children	None		
Elementry school age children	None		
Visually impaired (white cane/helper dog)	None		
Elderly/disabled (except wheelchairs)	None		
Wheelchairs/electric scooters	None		
Other (describe)	None	None	

Count Information

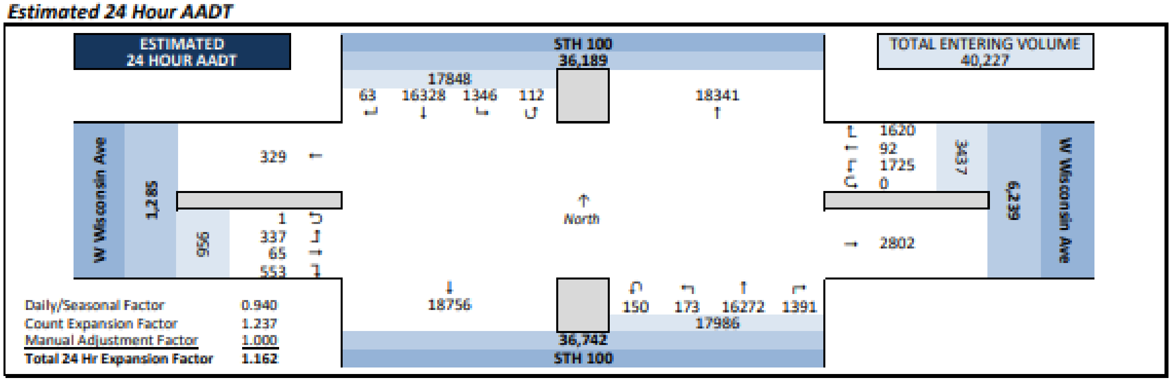
Hrs Counted:	6:00 AM-7:00 PM		
1st Day of Count	Thursday, March 12, 2020	Weather	
AM Peak Period	Thursday, March 12, 2020	Clear & Dry	
Midday Peak Period	Thursday, March 12, 2020	Clear & Dry	
PM Peak Period	Thursday, March 12, 2020	Clear & Dry	
Calculated Peak Hours			
AM 7:30-8:30am	MD 12:00-1:00pm	PM 4:15-5:15pm	
Peak Hours Selected for Analysis			
AM 7:30-8:30am	MD 12:00-1:00pm	PM 4:15-5:15pm	
Daily/Seasonal Adjustment Group	(2) Urban Arterials & Collectors		
Count Expansion Group	(2) Urban Arterials & Collectors		
Daily/Seasonal Adjustment Factor	0.940	Count Expansion Factor	1.237
Company Name	Ayres Associates	Manual Adj.	1.000
Observers: AM Peak Period	Miovision Video Recording		
Observers: Midday Peak Period	Miovision Video Recording		
Observers: PM Peak Period	Miovision Video Recording		
Comments	2017 DOT Seasonal Factors		

Observed 13 Hour Volume Summary





Estimated 24 Hour AADT



Traffic Signal Timing

Timing Cover Sheet for Signal: S1359 HWY: 100 and W Wisconsin Ave

Date: 2/25/2021
Signal No: S1359
County: MIL
Controller: Econolite
School: None

Changes Made By: D. Wolford
Highway: 100
Local Hwy: N Mayfair Rd
Location: W Wisconsin Ave
Ped: Standard

Pre-emption

Preemption:	Type:	Phases:
Emergency-Emitter	3M Opticom	2+5, 6+1, 4+7, 8+3

Municipal Id: None
EVP Contact:
Community: City of Wauwatosa
Contact Phone:
Email:

Coordination

System No: SS-40-0013
Coordination Type: Adaptive
Comm Type: Fiber

Controller IP Address: 172.22.69.122
Comments: Adaptive Coordination.
Processor IP: 172.22.69.124

	Length	Split 1	Split 2	Split 3	Split 4
Cycle 1=	150 sec	6:30am - 9:15am M-F 12:00pm - 4:00pm S-S			
Cycle 2=	130 sec	9:15am - 3:00pm M-F; 6:30pm - 9:00pm M-F; 8:45am - 12:00pm S-S; 4:00pm - 9:00pm S-S			
Cycle 3=	150 sec	3:00pm - 6:30pm M-F			
Cycle 4=					

Cabinet Type: TS2

☐ Battery Backup

Part of a Local System: No

Local Contact:
Phone Number:

Overlaps

Overlap A = Phases:
Overlap B = Phases:
Overlap C = Phases:
Overlap D = Phases:

Turn Operations

Phases with

FYA TOD ☐
5 Section Head ☐
Lead/Lag ☐

Phase Omit ☐
Dynamic FYA ☐
Split Phase ☐

Detector Timing

Dilemma Zone: No   Bike Detection ☐   Detection Type(s): Radar

Detector Number	**	21	41	61	81	82								
Stretch		*	*	*	*									
Right Turn Delay	**					*								
Left Turn Delay	**													

Unique Features

* See program for detector settings
Cycle lengths and splits correspond to backup timing plan.
** See InSync WebUI for details (configure detectors)
InSync Program: Manual Action Plan 90 (MM-5-1)
Backup Program: Manual Action Plan 0

Wisconsin DOT

ECONOLITE

MOVING TRAFFIC FORWARD

S 40-1359 - STH 100 & Wisconsin Ave - Econolite Type - ASC/3

Controller Timing Plan (MM) 2-1

Plan 1

Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Direction																
Min Green	5	10	5	5	5	10	5	5	0	0	0	0	0	0	0	0
Bk Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CS Min Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Delay Green	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk	0	7	0	7	0	7	0	7	0	0	0	0	0	0	0	0
Walk2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Walk Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear	0	11	0	43	0	20	0	39	0	0	0	0	0	0	0	0
Ped Clear 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped Clear Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ped CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle Ext	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vehicle Ext 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max1	20	45	20	35	20	45	20	35	0	0	0	0	0	0	0	0
Max2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYM Max	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dym Step	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow	3.5	4.0	3.5	5.7	3.5	4.0	3.5	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Clear	2.0	2.7	2.0	3.0	2.0	2.7	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red Revert	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Act B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sec/Act	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Int	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time B4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cars Wt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
STPTDuc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TTReduc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Min Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Crash Data

DTSD – SE Region
Intersection Safety Evaluation

Intersection Description

Intersection: STH 100 & Wisconsin Avenue

County: Milwaukee **Municipality:** City of Wauwatosa

Request for Evaluation

Reason for Request: Safety review

Requested By: N/A **Request Date:** N/A

Completed By: N/A **Completion Date:** N/A

Crash Data

Crash Rate	Crashes by Year		Crashes by Severity				
	Year	Total Crashes	K	A	B	C	PDO
.32	2016						
	2017						
(Crashes/ Million Entering Veh.)	2018	8				3	5
Fatal and Injury %	2019	4				2	2
	2020	2					2
36%	**Total**	14				5	9
	Avg.	**4.67**	**24hr Entering Volume / ADT**			**40,227**	
	Pre 2021	*5*	Year of Count			**2020**	

Crash Rate= (Avg. # of crashes*10^6) / (365*ADT) Preliminary 2021/22 crashes not included in calculations

HSM spreadsheet: \\dotwkefile1p\N3PUBLIC\SPO\Operations\Safety\Intersection, Segment & Project Files\SER Signal Safety.xlsx (*Add crash and volume statistics*)

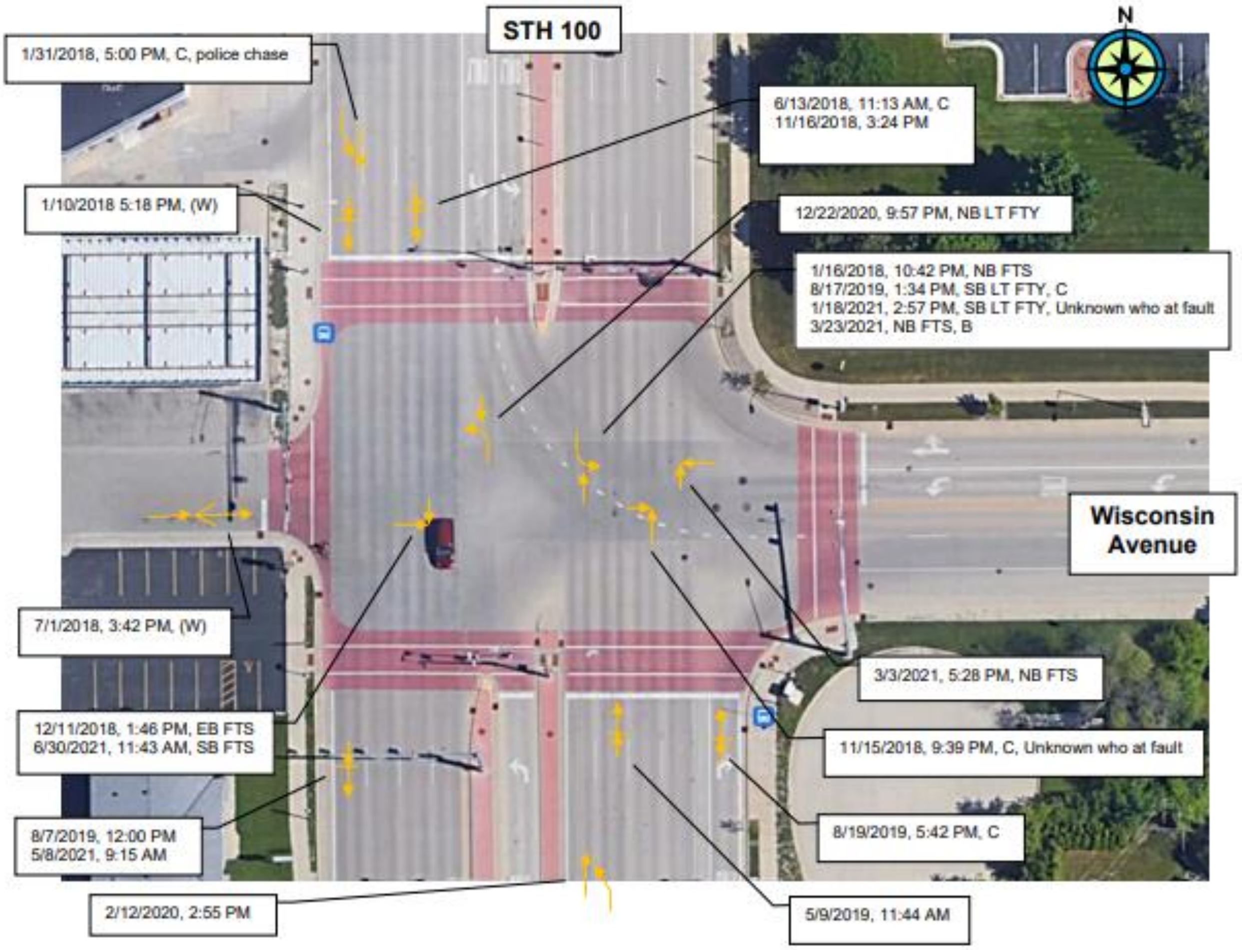
History, Safety Issues and Actions Taken

Changes During Study Period:	
Safety Issues:	
Actions:	

DTSD – SE Region
Intersection Safety Evaluation

STH 100 & Wisconsin Avenue

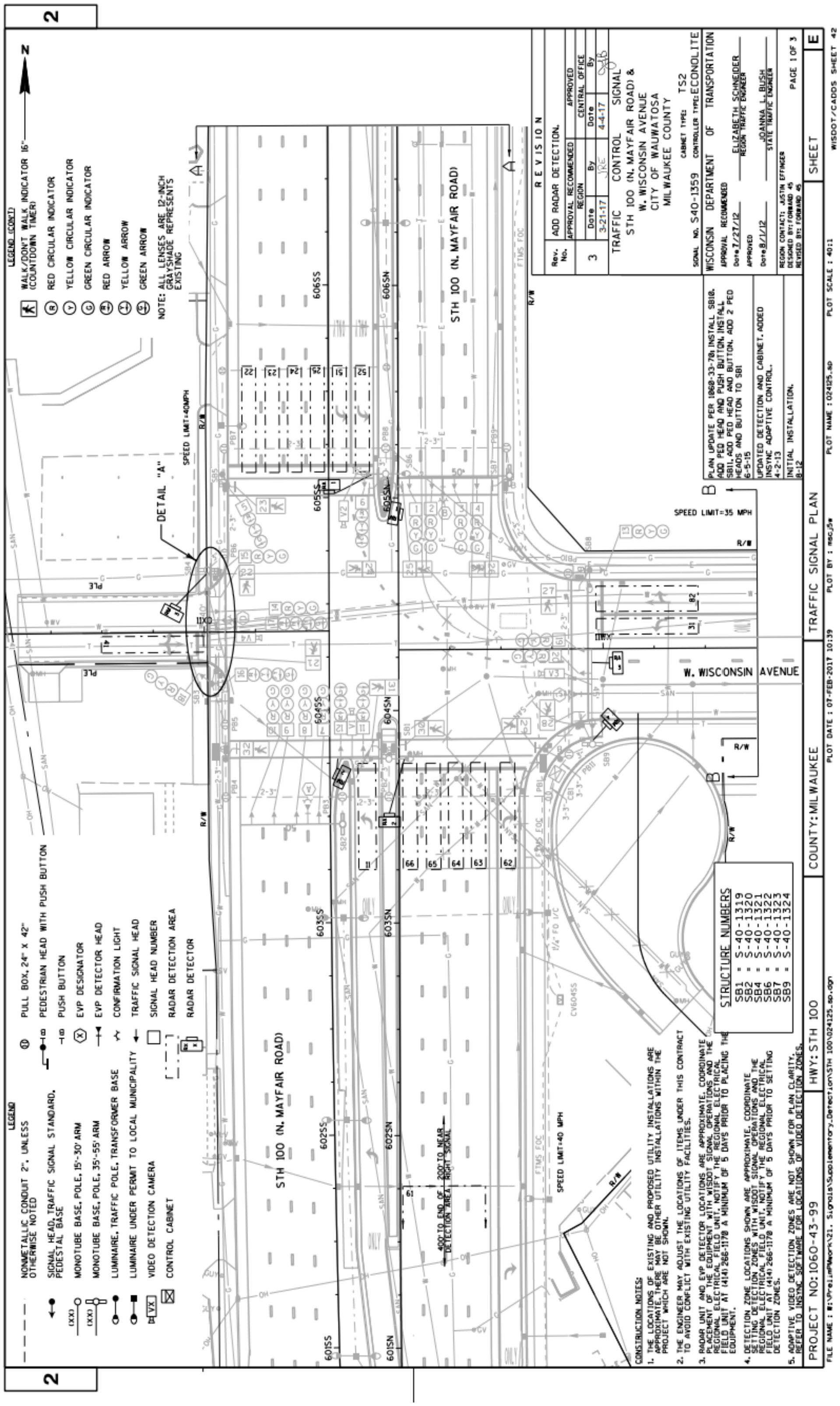
Milwaukee County — **January 2018-Preliminary 2021**



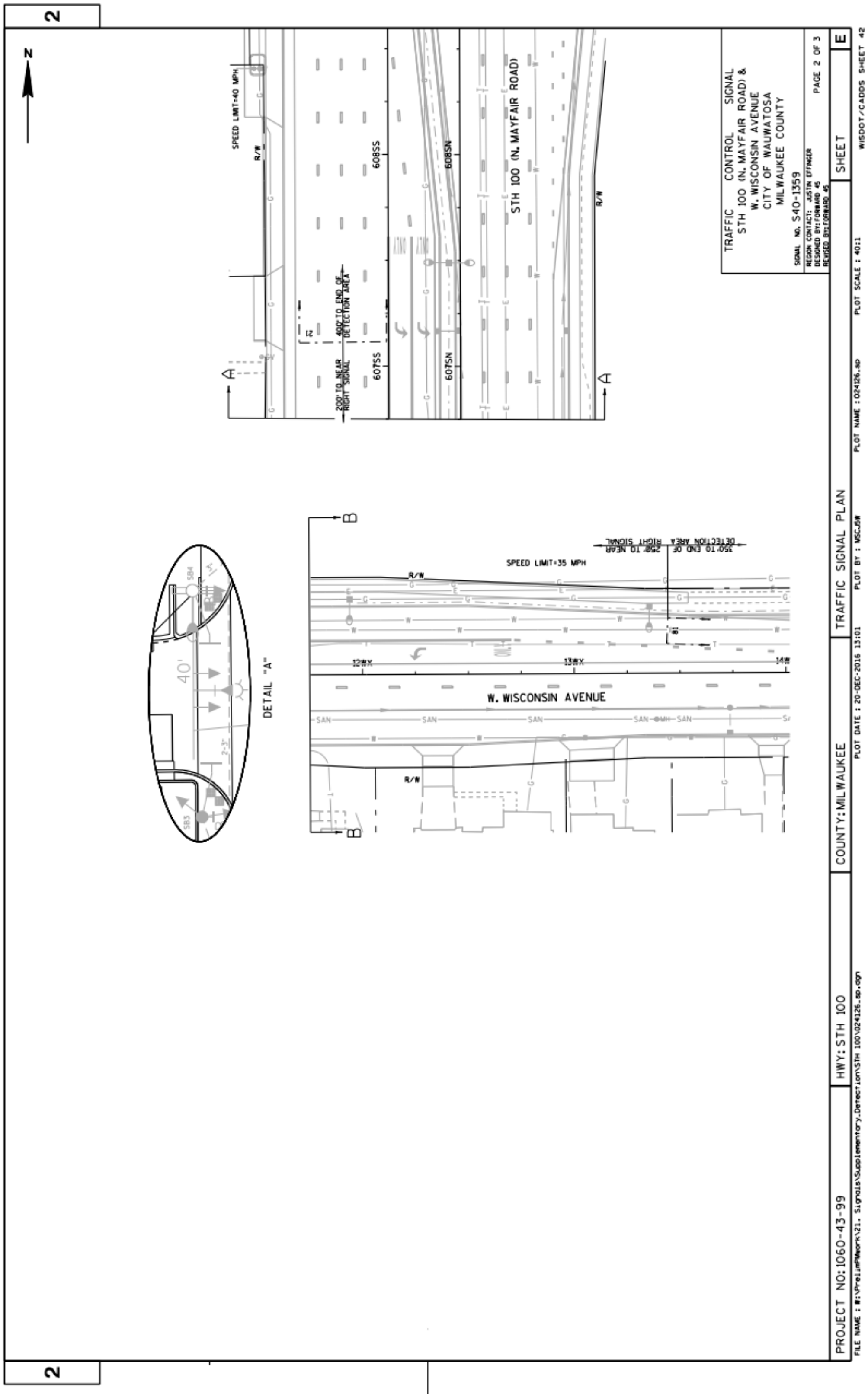
LEGEND

Signal/Sign Post	Bicycle	Right Angle	Out of Control	(S) = SNOW-ICE	K = FATAL
Tree/Utility Pole	Pedestrian	Left Turn	Rear-End	(W) = WET	A = SUS. SERIOUS INJURY
Non-Fixed Object	Non-Contact Vehicle	Right Turn	Head-On	(F) = FOG-MIST	B = SUS. MINOR INJURY
Fixed Object	Backing Vehicle	Sideswipe-Same	Overtake	(DUI) = ALCOHOL	C = POS. INJURY
Parked Vehicle	Moving Vehicle	Sideswipe-Opp.	Overturn	OR DRUG USE	BLANK = PROPERTY

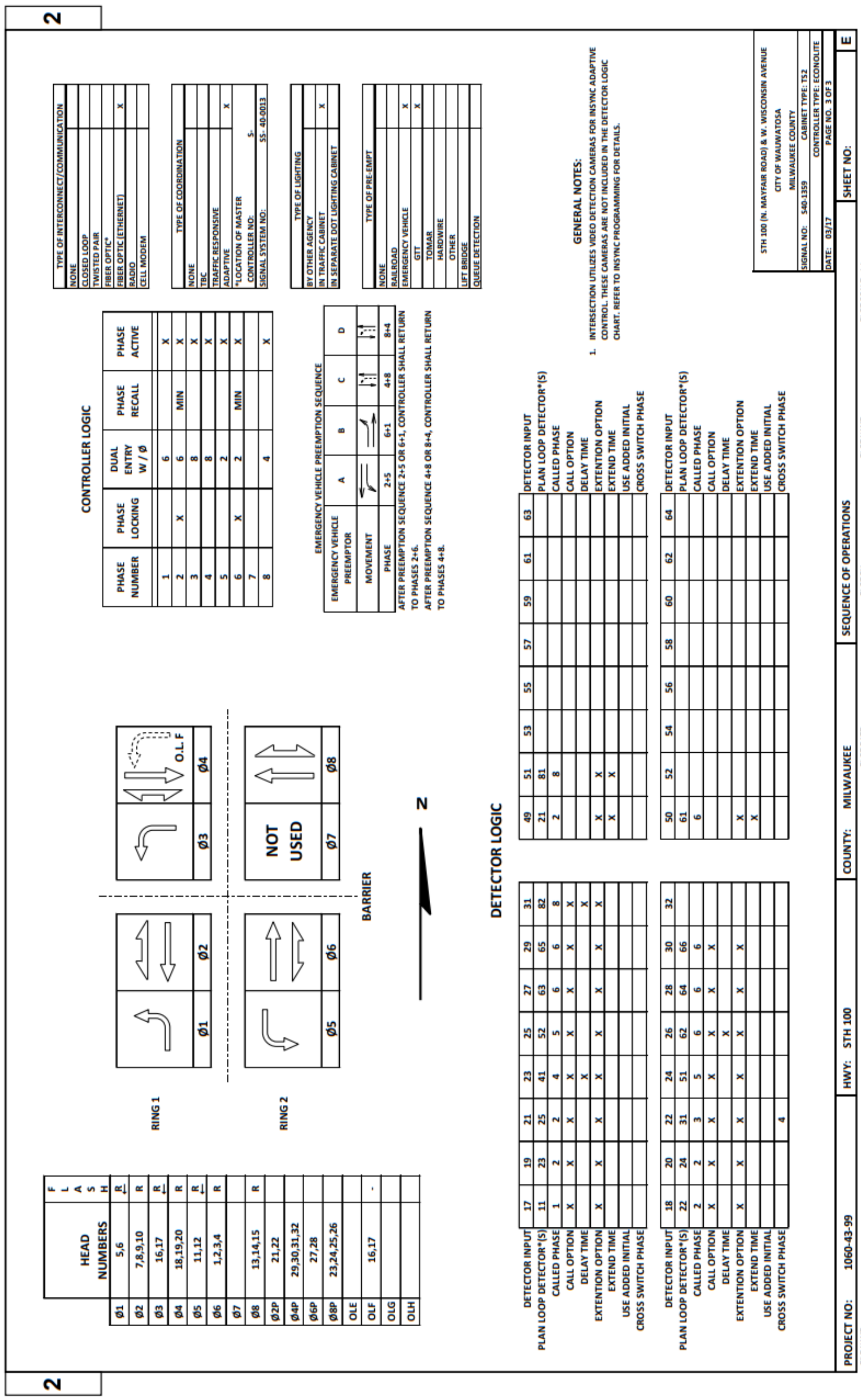
Traffic Signal Plan



Traffic Signal Plan



Traffic Signal Plan Controller Logic



	HEAD NUMBERS	FLASH
Ø1	5,6	R←
Ø2	7,8,9,10	R
Ø3	16,17	R←
Ø4	18,19,20	R
Ø5	11,12	R←
Ø6	1,2,3,4	R
Ø7		
Ø8	13,14,15	R
Ø2P	21,22	
Ø4P	29,30,31,32	
Ø6P	27,28	
Ø8P	23,24,25,26	
OLE		
OLF	16,17	-
OLG		
OLH		

CONTROLLER LOGIC

PHASE NUMBER	PHASE LOCKING	DUAL ENTRY W / Ø	PHASE RECALL	PHASE ACTIVE
1		6		X
2	X	6	MIN	X
3		8		X
4		8		X
5		2		X
6	X	2	MIN	X
7				
8		4		X

EMERGENCY VEHICLE PREEMPTION SEQUENCE

EMERGENCY VEHICLE PREEMPTOR	A	B	C	D
MOVEMENT				
PHASE	2+5	6+1	4+8	8+4

AFTER PREEMPTION SEQUENCE 2+5 OR 6+1, CONTROLLER SHALL RETURN TO PHASES 2+6.
AFTER PREEMPTION SEQUENCE 4+8 OR 8+4, CONTROLLER SHALL RETURN TO PHASES 4+8.

TYPE OF INTERCONNECT/COMMUNICATION	
NONE	
CLOSED LOOP	
TWISTED PAIR	
FIBER OPTIC*	
FIBER OPTIC (ETHERNET)	X
RADIO	
CELL MODEM	

TYPE OF COORDINATION	
NONE	
TBC	
TRAFFIC RESPONSIVE	
ADAPTIVE	X
*LOCATION OF MASTER CONTROLLER NO:	S-
SIGNAL SYSTEM NO:	SS- 40-0013

TYPE OF LIGHTING	
BY OTHER AGENCY	
IN TRAFFIC CABINET	X
IN SEPARATE DOT LIGHTING CABINET	

TYPE OF PRE-EMPT	
NONE	
RAILROAD	
EMERGENCY VEHICLE	X
GTT	X
TOMAR	
HARDWIRE	
OTHER	
LIFT BRIDGE	
QUEUE DETECTION	

DETECTOR LOGIC

DETECTOR INPUT	17	19	21	23	25	27	29	31
PLAN LOOP DETECTOR*(S)	11	23	25	41	52	63	65	82
CALLED PHASE	1	2	2	4	5	6	6	8
CALL OPTION	X	X	X	X	X	X	X	X
DELAY TIME				X				X
EXTENTION OPTION	X	X	X	X	X	X	X	X
EXTEND TIME								
USE ADDED INITIAL								
CROSS SWITCH PHASE								

DETECTOR INPUT	49	51	53	55	57	59	61	63
PLAN LOOP DETECTOR*(S)	21	81						
CALLED PHASE	2	8						
CALL OPTION								
DELAY TIME								
EXTENTION OPTION	X	X						
EXTEND TIME	X	X						
USE ADDED INITIAL								
CROSS SWITCH PHASE								

DETECTOR INPUT	18	20	22	24	26	28	30	32
PLAN LOOP DETECTOR*(S)	22	24	31	51	62	64	66	
CALLED PHASE	2	2	3	5	6	6	6	
CALL OPTION	X	X	X	X	X	X	X	
DELAY TIME					X			
EXTENTION OPTION	X	X	X	X	X	X	X	
EXTEND TIME								
USE ADDED INITIAL								
CROSS SWITCH PHASE			4					

DETECTOR INPUT	50	52	54	56	58	60	62	64
PLAN LOOP DETECTOR*(S)	61							
CALLED PHASE	6							
CALL OPTION								
DELAY TIME								
EXTENTION OPTION	X							
EXTEND TIME	X							
USE ADDED INITIAL								
CROSS SWITCH PHASE								

GENERAL NOTES:

1. INTERSECTION UTILIZES VIDEO DETECTION CAMERAS FOR INSYNC ADAPTIVE CONTROL. THESE CAMERAS ARE NOT INCLUDED IN THE DETECTOR LOGIC CHART. REFER TO INSYNC PROGRAMMING FOR DETAILS.

STH 100 (N. MAYFAIR ROAD) & W. WISCONSIN AVENUE
CITY OF WAUWATOSA
MILWAUKEE COUNTY
SIGNAL NO: S40-1359 CABINET TYPE: TS2
CONTROLLER TYPE: ECONOLITE
DATE: 03/17 PAGE NO. 3 OF 3

PROJECT NO: 1060-43-99 | HWY: STH 100 | COUNTY: MILWAUKEE | SEQUENCE OF OPERATIONS | SHEET NO: | E

FILE NAME : PLOT DATE : PLOT BY : PLOT NAME : PLOT SCALE : 1:1

Appendix B: Collected Data

Two datasheets are supplied. The first datasheet is the average speed, and the second datasheet is the average deceleration rate of vehicles. The data were collected on January 24th, 2022.

Average Speed Datasheet

Date & Time	Jan 24 2021; 9:45-10:15	Inspector	Cierra Smith & Ben Quintero
Temperature	18 degrees	Pavement Condition	poor, slushy, not plowed
Snow Accumulation	1-3 inches	Driver Visibility	Blowing Snow
Intersection	STH 100 and Wisconsin Avenue, Wauwatosa Wi		
Location of Radar	Wrong way / stop light warning sign		
Notes	40 MPH, stopped snowing when arrived - street not plowed - slow driving		
26	29	24	
35	31	28	
34	33	22	
22	27		
21	20		
19	32		
18	36		
20	31		
25	32		
24	29		
24	29		
26	28		
18	35		
32	36		
29	37		
26	36		
29	25		
27	29		
25	30		
31	31		
27	30		
28	36		
26	27		
29	24		
28	23		
26	42		
24	39		
25	38		
26	33		
30	21		
28	29		
32	30		
29	29		
35	23		
20	22		
31	25		
27	37		
26	36		
30	27		
28	22		
30	18		
21	25		
25	27		
24	26		
Average Speed (mph)	28.0		

Average Deceleration Rate Datasheet

Date	1/24/2022; 10:15-10:30	Inspector	Cierra Smith & Ben Quintero
Temperature	18 degrees	Pavement Condition	poor, slushy, not plowed
Snow Accumulation	1-3 inches	Driver Visibility	Blowing Snow
Intersection	STH 100 and Wisconsin Avenue, Wauwatosa WI		
Location of Radar	South end of cousins driveway; 230 feet approx		
Notes	40 MPH, stopped snowing when arrived - street not plowed - slow driving		
Distance Traveled (ft)	Starting Speed (mph)	Ending Speed (mph)	Deceleration Rate (ft/s^2)
230	25	0	2.94
230	19	0	1.70
230	22	0	2.27
230	20	0	1.88
230	24	0	2.71
230	16	0	1.20
230	17	0	1.36
230	19	0	1.70
230	15	0	1.06
230	27	0	3.42
230	24	0	2.71
230	23	0	2.49
230	18	0	1.52
230	21	0	2.07
230	17	0	1.36
230	22	0	2.27
230	22	0	2.27
230	22	0	2.27
230	18	0	1.52
230	24	0	2.71
230	15	0	1.06
Average Deceleration Rate (ft/s2)		2.02	

Civil Engineering

Capstone Report Approval Form

Master of Science in Engineering — MSCVE

Milwaukee School of Engineering

This capstone report, titled “Effect of Inclement Weather on the Timing of the Change Interval,” submitted by the student Cierra R. Smith, has been approved by the following committee:

Faculty Advisor: ________________________ Date: __19-May-2022_______

Dr. Mitzi Dobersek, PhD.

Faculty Member: ________________________ Date: __19-May-2022______

Dr. Jera Sullivan, PhD.

Faculty Member: ________________________ Date: _19-May-2022_______

Professor Kristen Belan