EXPERIMENTATION WITH COUNTDOWN PEDESTRIAN SIGNAL TIMING AND THE EFFECT ON INTERSECTION SAFETY

by

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ABSTRACT

Sixteen intersections in Newark, Delaware were studied to see if changes in countdown pedestrian signal timing effected intersection safety. Variations to signal timing were made at the point at which the zero indication on a countdown pedestrian signal synchronizes with the vehicular signal. A 'before and after' study was conducted using five years of crash records from the study intersections. A statistical analysis was performed on the data to study change in crash frequency, pedestrian crash frequency, and crash severity between three variations of signal timing. Results varied by intersection and between phases of the study. The results of this analysis confirm that no additional hazard was introduced by changing the synchronization of the countdown pedestrian signal from the start of yellow to the start of red. Additionally, changing the synchronization of the countdown pedestrian signal from the start of yellow to the start of red reduced crash severity.

DISCLAIMER

The data in this research was provided by the Delaware Department of Transportation (DelDOT) and consisted of crash records and summaries. The analysis and conclusions in this report are the work of the author and do not represent those of DelDOT.

Chapter 1

INTRODUCTION

This research questions the existing federal regulations on countdown pedestrian signal timing and evaluates a possible alternative in the interest of safety. Roadway intersections are one of the most complex and potentially dangerous situations in the transportation network. There are multiple conflict points between vehicles, bicycles, and pedestrians. As there are more drivers on the road each day, it is important to reduce any potential risks to road users. The modern traffic signal was developed to reduce conflicts between vehicles crossing paths at an intersection. Additionally, pedestrian signals were developed to reduce the risk of a vehiclepedestrian conflict. With the goal of making pedestrian signals safer, countdown signal heads were added to the traditional pedestrian signal head. This countdown timer displays the amount of time remaining for a pedestrian to cross the road. The intent is for pedestrians to use the information provided on a countdown pedestrian signal (CPS) to make safer decisions about crossing the road.

In addition to pedestrians using the countdown to know when to cross the road, drivers also have visibility of these signal heads as they approach an intersection. Drivers could potentially react in multiple ways when seeing the time remaining on the countdown: (1) drivers could increase speed to clear the intersection before the red indication, (2) drivers could apply the brakes earlier than expected creating the potential for rear-end collisions, or (3) drivers could use the information to apply safe judgment about when to stop at an appropriate speed. The information provided to

drivers and pedestrians has the potential to collectively influence intersection safety for all road users.

When CPS were adopted by the Federal Highway Administration (FHWA) in the Manual on Uniform Traffic Control Devices (MUTCD), the standards for installing and operating CPS were different from those established for traditional pedestrian signals. The 2003 MUTCD required the zero indication of a CPS to synchronize with the beginning of the concurrent vehicular yellow indication, while vehicles were still permitted to enter the intersection for several seconds. In contrast, traditional pedestrian signals allowed pedestrians to finish crossing the road during the yellow indication. This inconsistency between standards in the 2003 MUTCD could be confusing to pedestrians and may lead to contempt for the pedestrian signal leading pedestrians to cross after the end of the countdown and after the release of conflicting traffic.

When this research was initiated, the 2003 MUTCD was the most recent edition of the federal standard. Following the initiation of this study, the 2009 MUTCD was published which removed the inconsistency in standards, but allowed for more alternatives in signal timing. This will be discussed in more detail in chapter 3 as well as explaining why the project went ahead following the removal of the inconsistency.

The objective of this study is to evaluate if there is a safety concern with allowing the termination of the countdown timer to synchronize with the end of the concurrent vehicular yellow indication. A before and after study was conducted to evaluate intersection safety between three scenarios: (1) intersections with no CPS, (2) intersections with countdowns terminating at the beginning of yellow, and (3)

intersections with countdown terminating at the beginning of red. Each signal timing scenario was evaluated for crash frequency of all types of crashes, crash frequency of pedestrian crashes, and crash severity of all types of crashes. A statistical analysis was conducted using a 95% confidence interval to determine if there was a significant change between each scenario.

Chapter 2 of this thesis will provide more background on the situation that has been presented in this introduction. The literature review in chapter 3 will evaluate the existing research surrounding CPS. Following the literature review, chapter 4 will explain how the data was collected, processed, and analyzed. The results of this research is presented in chapter 5 and followed by an in depth discussion of the findings in chapter 6. Chapter 7 summarizes the discussion with clear conclusions that the reader should take away. This thesis also includes recommendations for future research on this topic and several appendices that contain detailed data and results from this analysis.

Chapter 2

BACKGROUND

This chapter serves as a foundation for the research that was conducted and leads into the data collection and methods of analysis. Federal standards and Delaware state practices are introduced to provide an understanding of the existing usage of Countdown Pedestrian Signals and an understanding of what motivated this study. Chapter 2 concludes with the research and results of the pedestrian observation study that was conducted before the crash analysis.

2.1 Manual on Uniform Traffic Control Devices

The Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) is a federal standard, which among other things governs the installation and operation of pedestrian traffic control devices. When this project was initiated, the 2003 MUTCD was the most recent edition. One of the functions of the MUTCD is to provide uniform standards for traffic control devises between states and classes of road. The first edition was developed and published in 1935 by a joint committee of members of the American Association of State Highway Officials (AASHO) and the National Conference on Street and Highway Safety (NCSHS). That committee is now referred to as the National Committee on Uniform Traffic Control Devices (NCUTCD) and contributes to periodic reviews of the MUTCD. The Federal Highway Administration (FHWA) has administered the MUTCD since 1971 [1].

The MUTCD uses very specific language to define its standards, guidance, and options. The following section includes paragraphs directly from the 2003 MUTCD to develop an understanding of pedestrian signal application.

The following definitions are provided in section 1A.13 of the 2003 MUTCD:

- Pedestrian Signal Head a signal head, which contains the symbols WALKING PERSON (symbolizing WALK) and UPRAISED HAND (symbolizing DON'T WALK), that is installed to direct pedestrian traffic at a traffic control signal.
- Walk Interval an interval during which the WALKING PERSON (symbolizing WALK) signal indication is displayed.
- Pedestrian Clearance Time the time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the traveled way or to a median.
- Pedestrian Change Interval an interval during which the flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication is displayed [1].

Two types of Pedestrian signal heads will be discussed in this report:

- 1. Traditional Pedestrian Signal (TPS)- a signal head, as defined above, as "Pedestrian Signal Head."
- 2. Countdown Pedestrian Signal (CPS) a signal head showing the same signal indications as the TPS with the addition of the countdown display. Figure 2.1 demonstrates the possible variations of pedestrian signal head designs.



Figure 2.1: Typical pedestrian signal indications, MUTCD 2009, Figure 4E-1 [2].

Section 4E.02 of the 2003 MUTCD details the meaning of pedestrian signal

head indications:

- A steady WALKING PERSON (symbolizing WALK) signal indication means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles. The pedestrian shall yield right-ofway to vehicles lawfully within the intersection at the time that the WALKING PERSON (symbolizing WALK) signal indication is first shown.
- A flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady WALKING PERSON (symbolizing WALK) signal indication shall proceed out of the traveled way.

- A steady UPRAISED HAND (symbolizing DON'T WALK) signal indication means that a pedestrian shall not enter the roadway in the direction of the signal indication.
- A flashing WALKING PERSON (symbolizing WALK) signal indication has no meaning and shall not be used [1].

Other standards in the 2003 MUTCD that are relevant to this study are listed

below. Section 4E.10 provides standards for TPS signals:

4E.10.01: When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder.

4E.10.02: A pedestrian clearance time shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication. The first portion of the pedestrian clearance time shall consist of a pedestrian change interval during which a flashing UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed. The remaining portions shall consist of the yellow change interval and any red clearance interval (prior to a conflicting green being displayed), during which a flashing or steady UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed.

4E.10.03: If countdown pedestrian signals are used, a steady UPRAISED HAND (symbolizing DON'T WALK) signal indication shall be displayed during the yellow change interval and any red clearance interval (prior to a conflicting green being displayed) [1].

In addition to these signal indications, a pedestrian change interval countdown

display can be used at intersections to inform pedestrians of the number of seconds

remaining in the pedestrian change interval. Section 4E.07 of the 2003 MUTCD

provides standards for CPS signals:

4E.07.02: If used, the display of the number of remaining seconds shall begin only at the beginning of the pedestrian change interval. After the countdown displays zero, the display shall remain dark until the beginning of the next countdown.

4E.07.03: If used, the countdown pedestrian signal shall display the number of seconds remaining until the termination of the pedestrian change interval. Countdown displays shall not be used during the walk interval nor during the yellow change interval of a concurrent vehicular phase [1].

This presents an inconsistency between standards for TPS and CPS. Both TPS and CPS pedestrian change intervals begin at the end of the walk interval, but the end of the pedestrian change interval, as shown by the end of the flashing upraised hand indication, is different. The flashing upraised hand indication for TPS can extend through the yellow and red indications of concurrent vehicular phases; where as, the flashing upraised hand indication for CPS is only permitted to extend to the end of the green indication of the concurrent vehicular phase. This difference in standards is potentially seen as confusing for pedestrians.

The Delaware Department of Transportation (DelDOT) began installing countdown indications at signals throughout Delaware in 2008, and all installations were consistent with the 2003 MUTCD requirements. The inconsistency between standards for TPS and CPS signal timing, as well as debate of this issue at the national level such as at the National Committee on Traffic Control Devices (NCUTCD), led to DelDOT's proposed experimentation in 2009 [3].

2.2 Application for Experimental Signal Timing

On May 19, 2009 DelDOT submitted a request for MUTCD experimentation to the FHWA. The request highlighted the false message given by the zero indication at the beginning of the yellow indication and the inconsistency between countdown and non-countdown pedestrian signals. The proposed experimentation would allow the countdown to continue through the yellow indication and reach zero at the end of the yellow phase. The original request was to conduct a before and after study at intersections, observing pedestrian behavior and testing the data collected for significant change. The FHWA responded on September 22, 2009 approving DelDOT's request.

2.3 Initial Pedestrian Behavior Study

Following the FHWA approval, the University of Delaware conducted a study to evaluate if there is a safety concern in allowing the pedestrian change interval to terminate at the end of the concurrent vehicular yellow interval using countdown pedestrian indications [3]. The study used observations of pedestrian behavior at 16 test intersections in Newark, Delaware in a before and after study. The study was divided into two stages. During stage one, the CPS countdown terminated at the end of the green interval. Signal timing was then changed in stage two so that the CPS countdown terminated at the end of the yellow interval. The alternative timing used in stage two is in conflict with the 2003 MUTCD standards for CPS but compliant for TPS.

Pedestrian behaviors were compared between the two stages to determine if there was a significant change in pedestrian safety. Observations of pedestrian behavior counted each of the following:

- Pedestrians using the crosswalk during the observation interval.
- Pedestrians who crossed in compliance with the signal.
- Late Starts Entered the intersection after the start of the flashing upraised hand signal.
- Late Arrivals Exited the crosswalk after the start of the steady upraised hand signal.

- Late Start-Early Arrival Entered the crosswalk after the start of the flashing upraised hand signal and exited before the start of the steady upraised hand signal.
- Late Start-Late Arrival Entered the crosswalk after the start of the flashing upraised hand signal and exited after the start of the steady upraised hand signal.
- Jaywalking Any crossing at or near the crosswalk in violation of the pedestrian signal.
- Pedestrian-Vehicle Conflicts Any interference between a pedestrian and a vehicle during the observation period.

The results of this study are presented in section 2.7 of this report.

2.4 Site Selection

Sixteen intersections were selected in in Newark, Delaware that represented a variety of intersection types. Intersections varied by urban and suburban areas, functional classification of intersecting streets, and the number of approaches to the intersection. Five of the intersections were three-way signalized intersections and the remaining eleven intersections were four-way signalized intersections. Figure 2.2 below shows the location of each intersection and includes a small map insert that shows the location of the study area in relation to northern Delaware.



Figure 2.2: Map of sixteen study intersections

2.5 Signal Timing Variations

Vehicular signal timing, and consequently pedestrian signal timing is unique at most intersections and is based on roadway alignment and vehicle and pedestrian volumes. Based on this understanding, each of the study intersections has slightly different phasing requirements for the CPS. The different control schemes used by DelDOT determine if the countdown signal face will synchronize with the concurrent vehicular interval in both stage one and stage two. From a driver's perspective, this synchronization determines if the countdown to zero on the CPS facing the vehicle as it approached the intersection will terminate at the same time the traffic signal displays yellow (stage one) or red (stage two). The following list outlines the possible scenarios present at the study intersections:

- 1. For pedestrian phases that are concurrent with the main street vehicular phase in a coordinated corridor, the countdown will always synchronize.
- 2. For pedestrian phases that are concurrent with the side street vehicular phase in a coordinated corridor, the countdown will only synchronize if the pedestrian split is greater than or equal to the vehicular split. (Variable by time of day)
- 3. For pedestrian phases at non-coordinated signals, countdown synchronization will only occur if the pedestrian split is greater than or equal to the vehicular split. (Variable by time of day)
- 4. For pedestrian phases at pre-timed intersections, countdown synchronization will always occur [3].

Of the 16 study intersections, eight are fully synchronized on both major and minor approaches, four are synchronized only on the major approach only, two are synchronized on the minor approach only, and two intersections were not synchronized on any approach (Table 2.1)

Intersection Number	Signal Permit	Intersection Location	CPS Synchronized With Concurrent Vehicular Phase
1	N423T	E Main St & Library Ave	Yes (Major Road Only)
4	N714T	E Main St & Pomeroy Lane	Yes
9	N428T	Delaware Ave & S College Ave	Yes
11	N430T	Delaware Ave & S Chapel St	Yes (Minor Road Only)
14	N424T	Delaware Ave & Library Ave	Yes
17	N431T	Cleveland Ave & N Chapel St	No
19	N439T	Cleveland Ave & New London Rd	Yes (Major Road Only)
22	N414T	Elkton Rd & Apple Rd	Yes
25	N411T	Elkton Rd & Thorn Ln	No
28	N436	S College Ave & SR 4	Yes
29	N467T	S College Ave & Marvin Dr	Yes
32	N438T	S College Ave & E Park Pl	Yes (Major Road Only)
34	N448T	S College Ave & Amstel Ave	Yes (Minor Road Only)
35	N663T	Hillside Rd & Apple Rd	Yes
39	N241	SR 4 & Robscott Manor	Yes (Major Road Only)
40	N346	SR 4 & SR 72	Yes

Table 2.1: Study intersections and signal synchronization [3].

2.6 Introduction of the 2009 MUTCD

Following the approval of experimental timing and prior to the installation of the CPS signal heads, the FHWA published the 2009 MUTCD. The 2009 MUTCD removed the inconsistency between CPS and TPS timing related to the termination of the pedestrian change interval, but provided more alternatives for CPS timing. Figure 2.3 below, graphically depicts the possible scenarios for CPS timing. In the center of the figure are five bars that show the vehicular phase intervals and their relationship to the CPS timing. The second bar is the equivalent of stage one of the pedestrian observation study, which is compliant with the 2003 MUTCD.

All CPS timing scenarios used in the 2009 MUTCD require a 3-second buffer interval between the termination of the pedestrian change interval and the release of any conflicting vehicular traffic. Standard DelDOT practice is to use a 2-second all-

red interval, where no through or left turning movements are permitted. Longer all-red intervals are implemented on a case by case basis as needed. All intersections in this study used 2-second all-red intervals for all phases. Therefore, the experimental timing was only different by one second compared to what is specifically allowed in the 2009 MUTCD. Despite the new MUTCD and very minor difference between the allowable pedestrian timings and experimental approval, it was decided to conduct this study for several reasons. First, this topic has not been well evaluated by other research. Second, the 3-second buffer included in the MUTCD is based on the joint engineering judgment of the NCUTCD and FHWA MUTCD Team, and is not based on documented research [3].

The section of the 2009 MUTCD relevant to this study is listed below:

4E.07.06: The countdown pedestrian signal shall display the number of seconds remaining until the termination of the pedestrian change interval (flashing UPRAISED HAND). Countdown displays shall not be used during the walk interval or during the red clearance interval of a concurrent vehicular phase [2].



Figure 2.3: Pedestrian intervals, MUTCD 2009, Figure 4E-2 [2].

2.7 Pedestrian Behavior Results

The results presented in this section are from the 2011 study by Lee, Bedeley, Luszcz, *MUTCD Experimentation with Countdown Pedestrian Signals and Change Intervals*. Through pedestrian observations at the 16 study intersections, it was found that there was a statistically significant reduction in jaywalking between phase-2 and phase-3 (before and after synchronization to the start of the red interval). This was calculated as the change in percentage of all pedestrians crossing at or near the intersection that jaywalked. Jaywalking is defined as, any crossing at or near the crosswalk in violation of the pedestrian signal. Jaywalking is considered dangerous

pedestrian behavior that can lead to increased risk of vehicle-pedestrian crashes. A reduction in jaywalking can be seen as an improvement in intersection safety. However, without additional studies it cannot be said that this change of synchronization of the countdown display was directly attributable to the reduction in jaywalking observed. Additional studies are needed which would isolate this issue from the other variables [3].

Among the other pedestrian behaviors observed, not including jay walking, there was not a significant change in pedestrian behavior between phase-2 and phase-3. The results of the pedestrian observation study indicate that the no increased hazard was introduced by changing the synchronization of the CPS from the start of yellow to the start of red [3].

Chapter 3

LITERATURE REVIEW

Countdown pedestrian signals (CPS) are relatively new in the field of traffic engineering and the full effects of this signal device are not yet known. Many municipalities and departments of transportation have recently initiated installation based on existing research. Several studies have evaluated the effect of CPS on pedestrian and driver behavior and how this relates to safety at signalized intersections. We are not aware of any studies that have evaluated alternatives for the signal timing of CPS synchronized with concurrent vehicular signals. This literature review will summarize some of the relevant research that has been conducted on CPS and their effects.

The general literature on CPS is conclusive that the CPS is better understood than traditional pedestrian signals [4, 5]. The intent of the CPS installation is that with more information about the time remaining to cross a road, pedestrians will make safer judgments about crossing. The Highway Safety Manual (HSM) is published by the American Association of State Highway and Transportation Officials (AASHTO) and is one of the leading references used by engineers to conduct quantitative safety analysis of roadways and intersections. Part D of the HSM includes crash modification factors (CMF) that quantify the change in average crash frequency as a result of geometric or operational modifications to a site that differs from set base conditions. A CMF is only provided if AASHTO has reviewed the existing research and determined that it is reliable. If research is presented that has insufficient quantitative information but provides evidence of the effects on crash frequency the treatment is noted in the HSM, but a CMF is not published. The 2010 HSM includes "install pedestrian countdown signals" as one of those items that does not have sufficient quantitative research to publish a CMF. The one study on CPS cited in the HSM is by Eccles, et al. This before and after study measured the effect of CPS on pedestrian and motorist behavior at five intersections in Montgomery County, Maryland in 2004 [6]. The section of this study provided in the 2010 HSM states that, "installing pedestrian countdown signals appears to reduce pedestrian-motor vehicle conflicts at intersections. There appears to be no effect on vehicle approach speeds during the pedestrian clearance interval (i.e., the flashing DON'T WALK) with the countdown signals" [7].

In 2001, the San Francisco Department of Parking and Traffic conducted one of the early pilot studies on CPS installation. CPS signals were installed at 14 signalized intersections. The focus of the study was to evaluate the: effect on pedestrian injuries; effect on pedestrian behavior; effect on driver behavior, especially running red lights; favorability among pedestrians; and, effectiveness of the start of the countdown (at the start of the flashing hand). This was one look at signal timing but it did not look at the termination of the countdown or synchronization with vehicular signals. The intersections were selected based on higher than average pedestrian injuries. In some cases the city also made changes to signal timing at the time of CPS installation. Yellow phases were extended and all red intervals were introduced. This may have had an effect on safety independent of the CPS. Pedestrian crash rates were studied in a before and after study. The study results found that "the number of pedestrian injury crashes declined by 52% after the introduction of the countdown

signals." However there was a similar reduction in crash rates at intersections without CPS. This reduction could be contributed to regression to the mean, but it can be said that there was no hazard introduced with the CPS installation. 'Regression to the mean' is a term used in statistical analysis when a change in crash frequency over a short period of time is not consistent with the greater trend over a longer period of time. In this context, the number of crashes reported at the intersection during the before phase could have been extremely high resulting in a false reduction in crashes when the number of crashes in the after phase were close to average. In the study of pedestrian behavior, they found that "The percentage of pedestrians still in the crosswalk when the signal turned red showed a significant decrease after the installation of CPS. The countdowns did not result in an increase in drivers running red lights [5].

In 2011, a study in Washington, D.C. evaluated the differences in pedestrian behavior between two scenarios for the countdown display on a CPS. One scenario started the countdown at the onset of the steady walking person and the second started the countdown at the beginning of the flashing upraised hand. Observations from 25 intersections were included in this comparative study. There were no significant differences in pedestrian behavior between countdown scenarios. However, 83% of drivers and 86% of pedestrians surveyed preferred the signal that started the countdown with the solid walk [4]. No other studies have compared alternatives for the initiation or termination of the countdown on CPS.

A before and after study of 106 intersections was conducted in Charlotte, North Carolina between 2000 and 2007. The study looked at the effect of installing CPS on vehicle-pedestrian crashes and vehicle only crashes. The results showed that

there was an insignificant decrease in vehicle-pedestrian crashes but a significant decrease in all crashes after installation of CPS. This study also found that CPS were most effective at high crash and high volume intersections [8]. It can be inferred that drivers were also using the information presented on the CPS to make safer driving decisions.

A ten-year study in Toronto, Canada concluded that the installation of CPS did not reduce the frequency of vehicle-pedestrian crashes at test intersections. The 'before and after' study used crash data from 1965 intersections collected between 2000 and 2009. Data was collected before and after CPS installation, so each intersection acted as its own 'control' for statistical analysis [9].

An observational study was conducted at two intersections in Berkeley, California. Two intersections were selected with similar geometry and volumes, CPS were installed at one intersection and not at the second. The observations focused on driver behavior during yellow and red phases. It was found that drivers at the intersection with CPS were less likely to enter the intersection after the beginning of the yellow signal [10]. This trend generally leads to safer intersections for drivers and pedestrians.

Another study evaluated the effect of CPS on vehicle speeds. The study was conducted at two intersections in Las Vegas, Nevada. Speeds were observed on two segments immediately upstream from the stop bar at signalized intersections. Speed observations were also compared based on the display of the CPS and the time remaining on the countdown timer. "Results do not indicate that speeds are affected by the actual numeric displays on the countdown timer." However, they did find that

speeds were higher when the CPS displayed the countdown timer and flashing don't walk indication [11].

In summary, the published research on CPS concludes that: (1) intersection safety does not get worse with the installation of CPS and in some situations intersection safety improves; (2) drivers are making better decisions based on the information provided by the CPS; (3) pedestrians are more compliant with CPS as compared to TPS; (4) the time displayed on a CPS does not influence vehicle speeds approaching an intersection; and, (5) CPS do not increase the number of vehicles running red lights.

The research conducted in this study is unique and will contribute to the existing understanding of the effects of the installation and operation of CPS on public safety.

Chapter 4

MATERIALS AND METHODS

4.1 Data Collection

This study addresses the question: Is there a safety concern with allowing pedestrian countdown signals to terminate (reach zero) at the end of the concurrent vehicular yellow phase? The earlier pedestrian observation study conducted by the University of Delaware and the Delaware Department of Transportation (DelDOT) concluded that there was not a significant change in pedestrian behavior following the change in signal timing [3]. This research takes a long-term look at crash records from intersections as a method of analyzing intersection safety related to the change in pedestrian signal timing. DelDOT provided five years of crash records and summaries for each of the sixteen study intersections. A statistical analysis was conducted to determine if there was a significant change in crash frequency and/or crash severity. Vehicle and pedestrian volumes were not available for all of the sixteen study intersections, so it was not possible to incorporate this data into the analysis.

Crash data was collected from January 1, 2007 through February 29, 2012. The data was processed through the Delaware Crash Analysis Reporting System (CARS), which provides a level of consistency in data that is not available in some states. All reporting agencies in Delaware use the same format for reporting crashes. This consistency removes some uncertainty in the interpretation of crash records, as each factor is given an alphanumeric code. One of the data points provided in the CARS report is the First Harmful Event of a crash. This describes the initial action of the

vehicle or object impacted by the vehicle that led to the crash being reported. There are 43 categories of first harmful events including unknown types.

Only reportable crashes were used in this study. Reportable crashes are specified by Delaware State Code as: a collision resulting in injury or death to any person; a collision on a public road resulting in property damage greater than \$1,500; and, a collision involving a driver impaired by drugs and or alcohol [12].

4.2 Crash Data Analysis

The crash data was separated by intersection and phase. At each of the sixteen intersections, the transition from phase-1 to phase-2 was unique and depended on the date of the physical installation of the countdown pedestrian signal. The transition from phase-2 to phase-3 was uniform, as the DelDOT Transportation Management Center (TMC) in Smyrna, Delaware controlled the signal timing remotely.

The three phases of this study are as follows:

- 1. Phase 1 Intersections with no CPS
- 2. Phase 2 Intersections with CPS. Countdown to zero terminates at the beginning of the concurrent vehicular yellow indication. This timing is compliant with the 2003 MUTCD.
- 3. Phase 3 Intersections with CPS. Countdown to zero terminates at the beginning of the concurrent vehicular red indication. This is the approved experimental CPS timing.

Phase-1 started on January 1, 2007 and ended the day before installation of the countdown pedestrian signal, which was unique for each intersection. Phase-2 started the day of installation of the countdown pedestrian signal and ended on September 29, 2010 with the last day of MUTCD compliant signal timing. The earliest date of installation was on January 6, 2009 and the latest date was on August 3, 2010. Phase-3

started on September 30, 2010 with the first day of experimental signal timing and ended February 29, 2012.

The crash data was analyzed in three ways:

- 1. Crash frequency all crash types
- 2. Pedestrian crash frequency only vehicle-pedestrian collisions
- 3. Crash severity all crash types

The following two sections will explain how the statistical analysis was conducted on the crash data.

4.2.1 Crash Frequency

Crash frequency, as used in this study, is defined as the average number of crashes per month at a single study intersection. Two values were collected from the crash data: average crashes per month and standard deviation of crashes per month.

A two-sample t-test was conducted to determine whether there was a statistically significant difference in the average number of crashes between phases at a 95 percent confidence level. The null hypothesis was defined as the difference in the average number of crashes between phases as equal to zero. The alternative hypothesis was defined as the difference in the average number of crashes between phases as not equal to zero. The t-value provides the number of standard deviations above or below the null hypothesis value, also known as the test statistic. The P-value provides the smallest level at which the difference in average crashes is significant. If the test statistic is greater than zero and the level of significance (P-value) is less than 0.025, one can say with a 95 percent confidence that the number of crashes reduced between phases. If the test statistic is less than zero and the level of significance (P-value) is less than 0.025, one can say with a 95 percent confidence that the number of crashes increased between phases.

Intersections were studied individually to see if there was a change in crash frequency between phases. Since there were relatively few months in this study and a low number of crashes at some intersections, the data from all intersections was aggregated and compared by phase in addition to the individual intersections. This enabled us to use a larger sample size in the calculations and gives a broader look at the effect of signal timing changes. The aggregated analysis can reduce the impact of an individual intersection and focus on the average trend between phases. The results of the aggregated analysis are presented alongside the individual intersections.

This analysis was initially performed on data including crashes of all types of first harmful events and a second time on data from only pedestrian crashes as determined by first harmful event. The results are shown in Chapter 5.

4.2.2 Crash Severity

Following the crash frequency analysis, crash severity was compared between phases to see if there was a significant change and to see if the change was different compared to crash frequency. Severity of a crash was based on the coding in the CARS data. Crash types were divided into three categories: fatality crash, personal injury crash, and property damage only. Non-reportable crashes were not included in this study. For each fatality and personal injury crash, the number of fatalities and injured persons was extracted.

To measure severity, crashes were weighted using an economic cost per crash. The cost was taken from the National Safety Council (NSC) website [13] that provides a dollar value for the expected economic impact of each of the three types of crashes

in this study. This type of cost estimate is widely used in public and private research to estimate the actual costs to society of deaths and injuries. "The costs are a measure of the dollars spent and income not received due to accidents, injuries, and fatalities" [13]. A fatal crash is given the highest cost of \$1,420,000 per fatality, followed by personal injury crashes at \$78,700 per person injured, and property damage only crashes costing \$9,100 per crash incident. These values are based on extensive research and past insurance claims.

By weighing each crash incident, it is possible to measure the change in severity of crashes between phases in this study. The first part of the study looked purely at the change in average number of crashes per month, the severity analysis determined if the average crash incident was more or less severe between each phase in this study.

To perform the severity analysis, each reportable crash was given a dollar value based on the National Safety Council data. For example, if there was a fatal crash with one fatality and four injuries, the cost would be $(\$1,420,000 \times 1) + (\$78,700 \times 4) = \$1,734,000$. If there were a property damage only crash, the cost would be \$9,100 independent of the number of vehicles or passengers involved. After the total cost per crash was calculated, two values were collected from the data: average cost per month, and standard deviation of cost per month.

The severity analysis was performed on all crash types as determined by first harmful event in the CARS report. The statistical analysis used in the crash severity analysis follows the same procedures detailed in Chapter 4.2.1. A two-sample t-test was conducted to determine whether there was a statistically significant difference in the average cost per month between phases at a 95 percent confidence level.

Calculations were performed using individual intersection data as well as aggregated data in the same method as the crash frequency analysis. The results are presented in Chapter 5.

Chapter 5

RESULTS

This chapter presents the results of the crash data analysis. The three methods of analysis (crash frequency, pedestrian crash frequency, and crash severity) are presented in separate sub-chapters. Within each method of analysis, each of the three phases of the study is compared and significant change is highlighted. The discussion chapter follows this chapter, and is where results will be presented in an analytical and conceptual framework to provide a better understanding and to draw conclusions.

5.1 Crash Frequency, All Crash Types

5.1.1 Crash Frequency, All Crash Types, Phase-1 to Phase-2

This portion of the study analyzed the change in crash frequency between an intersection with no CPS in phase-1 and the same intersection in phase-2 with an MUTCD compliant CPS. The results show that there was a significant decrease in crash frequency at 4 of 16 intersections, when MUTCD compliant CPS were installed at intersections where there was not a CPS previously. At 12 of 16 intersections there was not a significant change in crash frequency. Using aggregated data to compare phase-1 and phase-2, there was not a significant change in crash frequency when CPS were installed at intersections with MUTCD compliant timing.

Intersection	Location	Start Phase 1	End Phase 1	Start Phase 2	End Phase 2	t-statistic	P-value	Change
1	E Main St & Library Ave	01/01/2007	08/02/2010	08/03/2010	09/29/2010	-0.9	0.267	None
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	03/11/2010	09/29/2010	1.5	0.080	None
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	05/04/2010	09/29/2010	-0.6	0.287	None
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	06/17/2010	09/29/2010	1.6	0.080	None
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	02/12/2009	09/29/2010	0.0	0.500	None
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	03/10/2010	09/29/2010	1.1	0.144	None
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	08/03/2010	09/29/2010	4.8	0.000	Decrease
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	01/06/2009	09/29/2010	-0.6	0.276	None
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	04/14/2010	09/29/2010	-0.1	0.462	None
28	S College Ave & SR 4	01/01/2007	10/29/2009	10/30/2009	09/29/2010	1.2	0.122	None
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	07/08/2010	09/29/2010	-1.1	0.193	None
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/24/2009	09/29/2010	2.1	0.023	Decrease
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	07/08/2010	09/29/2010	3.1	0.002	Decrease
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	03/11/2010	09/29/2010	2.9	0.003	Decrease
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/18/2009	09/29/2010	-1.0	0.164	None
40	SR 4 & SR 72	01/01/2007	02/03/2010	02/04/2010	09/29/2010	-1.4	0.093	None
Analysis of Cl	nange With Aggregated Data from A	Il Intersections				-0.5	0.309	None

Table 5.1: Change analysis between phase-1 and phase-2, all crash types.

The average crash frequency in phase-1 was 1.13 crashes per month and 1.17 crashes per month in phase-2. The results of this analysis are shown above in Table 5.1 and more detailed data is provided in Appendix A. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.1.2 Crash Frequency, All Crash Types, Phase-2 to Phase-3

This portion of the study analyzed the change in crash frequency between an intersection with an MUTCD compliant CPS in phase-2 and the same intersection in phase-3 with experimental CPS timing.

Intersection	Location	Start Phase 2	End Phase 2	Start Phase 3	End Phase 3	t-statistic	P-value	Change
1	E Main St & Library Ave	08/03/2010	09/29/2010	09/30/2010	02/29/2012	0.9	0.267	None
4	E Main St & Pomeroy Lane	03/11/2010	09/29/2010	09/30/2010	02/29/2012	-0.7	0.247	None
9	Delaware Ave & S College Ave	05/04/2010	09/29/2010	09/30/2010	02/29/2012	1.1	0.162	None
11	Delaware Ave & S Chapel St	06/17/2010	09/29/2010	09/30/2010	02/29/2012	-1.3	0.121	None
14	Delaware Ave & Library Ave	02/12/2009	09/29/2010	09/30/2010	02/29/2012	-0.2	0.421	None
17	Cleveland Ave & N Chapel St	03/10/2010	09/29/2010	09/30/2010	02/29/2012	-0.2	0.422	None
19	Cleveland Ave & New London Rd	08/03/2010	09/29/2010	09/30/2010	02/29/2012	-3.1	0.003	Increase
22	Elkton Rd & Apple Rd	01/06/2009	09/29/2010	09/30/2010	02/29/2012	3.3	0.001	Decrease
25	Elkton Rd & Thorn Ln	04/14/2010	09/29/2010	09/30/2010	02/29/2012	0.7	0.253	None
28	S College Ave & SR 4	10/30/2009	09/29/2010	09/30/2010	02/29/2012	0.2	0.422	None
29	S College Ave & Marvin Dr	07/08/2010	09/29/2010	09/30/2010	02/29/2012	1.4	0.148	None
32	S College Ave & E Park Pl	09/24/2009	09/29/2010	09/30/2010	02/29/2012	-1.7	0.051	None
34	S College Ave & Amstel Ave	07/08/2010	09/29/2010	09/30/2010	02/29/2012	-2.6	0.010	Increase
35	Hillside Rd & Apple Rd	03/11/2010	09/29/2010	09/30/2010	02/29/2012	-1.0	0.166	None
39	SR 4 & Robscott Manor	09/18/2009	09/29/2010	09/30/2010	02/29/2012	1.4	0.089	None
40	SR 4 & SR 72	02/04/2010	09/29/2010	09/30/2010	02/29/2012	-1.5	0.075	None
Analysis of Cl	nange With Aggregated Data from A	All Intersections				1.0	0.159	None

Table 5.2: Change analysis between phase-2 and phase-3, all crash types.

The results of this study show that there was a significant decrease in crash frequency at 1 of 16 intersections and a significant increase at an additional 2 of 16 intersections. At the remaining 13 of 16 intersections there was not a significant change in crash frequency. Using aggregated data to compare phase-2 and phase-3, there was not a significant change in crash frequency. The average crash frequency in phase-2 was 1.17 and 1.08 in phase-3. The results of this analysis are shown below in Table 5.2 and more detailed data is provided in Appendix A. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.1.3 Crash Frequency, All Crash Types, Phase-1 to Phase-3

This portion of the study analyzed the change in crash frequency between phase-1 and phase-3. This transition is equivalent to installing a CPS with experimental timing at an intersection where there was not a CPS previously.

Intersection	Location	Start Phase 1	End Phase 1	Start Phase 3	End Phase 3	t-statistic	P-value	Change
1	E Main St & Library Ave	01/01/2007	08/02/2010	09/30/2010	02/29/2012	0.3	0.383	None
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	09/30/2010	02/29/2012	0.6	0.277	None
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	09/30/2010	02/29/2012	1.2	0.119	None
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	09/30/2010	02/29/2012	0.4	0.346	None
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	09/30/2010	02/29/2012	-0.2	0.421	None
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	09/30/2010	02/29/2012	1.0	0.162	None
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	09/30/2010	02/29/2012	1.0	0.162	None
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	09/30/2010	02/29/2012	2.3	0.014	Decrease
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	09/30/2010	02/29/2012	1.1	0.139	None
28	S College Ave & SR 4	01/01/2007	10/29/2009	09/30/2010	02/29/2012	1.5	0.071	None
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	09/30/2010	02/29/2012	1.3	0.101	None
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/30/2010	02/29/2012	0.4	0.346	None
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	09/30/2010	02/29/2012	-0.8	0.215	None
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	09/30/2010	02/29/2012	0.5	0.311	None
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/30/2010	02/29/2012	0.5	0.310	None
40	SR 4 & SR 72	01/01/2007	02/03/2010	09/30/2010	02/29/2012	-3.3	0.001	Increase
Analysis of Ch	nange With Aggregated Data from A	Il Intersections				0.8	0.212	None

Table 5.3: Change analysis between phase-1 and phase-3, all crash types.

The results show that 1 of 16 intersections experienced a significant decrease in crash frequency. Additionally, 1 of 16 intersections experienced a significant increase in crash frequency. Using aggregated data to compare phase-1 and phase-3, there was not a significant change in crash frequency. The average crash frequency in phase-1 was 1.13 and 1.08 in phase-3. The results of this analysis are shown below in Table 5.3 and more detailed data is provided in Appendix A. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.2 Pedestrian Crash Frequency Analysis

Pedestrian crash frequencies were compared between phases in the same method that all crash types were compared in the previous section. Over all, one intersection experienced a significant change in pedestrian crash frequency. The intersection of East Main Street and Pomeroy Lane experienced a significant decrease in pedestrian crash frequency between phase-1 and phase-2, and between phase-1 and phase-3. This intersection is unique in this study as it is a t-intersection of two oneway roads and includes a crossing of a major pedestrian/bicycle trail.

The average crash frequencies from each intersection were aggregated and compared by phase. There was a significant increase in pedestrian crash frequency between phase-1 and phase-2. However, there was a significant decrease in crash frequency between phase-2 and phase-3 as well as between phase-1 and phase-3. All of these results are accurate with a 95% confidence interval. One note to highlight is that the significant decrease in pedestrian crashes was observed when intersections were compared in two situations: first between intersections having no CPS to those having CPS with experimental timing, and secondly between intersections with MUTCD compliant CPS to those having CPS with experimental timing. One challenge in studying the pedestrian crashes was that there were so few incidents reported in the CARS data. Over the duration of this project there were 23 pedestrian crashes reported. At some intersections there were no reported pedestrian crashes,

which made it impossible to compare a change in crash frequency. This was the case at 12 of 16 intersections during at least one phase.

The results of this analysis are shown below in Tables 5.4, 5.5, and 5.6. More detailed data is provided in Appendix B. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

Table 5.4: Change analysis between phase-1 and phase-2, pedestrian crashes.

Intersection	Location	Start Phase 1	End Phase 1	Start Phase 2	End Phase 2	t-statistic	P-value	Change	
1	E Main St & Library Ave	01/01/2007	08/02/2010	08/03/2010	09/29/2010	-0.9	0.267	None	
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	03/11/2010	09/29/2010	2.1	0.022	Decrease	
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	05/04/2010	09/29/2010	1.0	0.162	None	
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	06/17/2010	09/29/2010	-0.9	0.217	None	
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	02/12/2009	09/29/2010	-1.0	0.165	None	
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	03/10/2010	09/29/2010	1.0	0.162	None	
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	08/03/2010	09/29/2010	No C	No Crashes Reported		
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	01/06/2009	09/29/2010	No C	rashes Rep	orted	
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	04/14/2010	09/29/2010	1.0	0.162	None	
28	S College Ave & SR 4	01/01/2007	10/29/2009	10/30/2009	09/29/2010	1.0	0.162	None	
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	07/08/2010	09/29/2010	No C	rashes Rep	orted	
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/24/2009	09/29/2010	1.4	0.086	None	
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	07/08/2010	09/29/2010	1.8	0.040	None	
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	03/11/2010	09/29/2010	No Crashes Reported			
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/18/2009	09/29/2010	No Crashes Reported			
40	SR 4 & SR 72	01/01/2007	02/03/2010	02/04/2010	09/29/2010	No Crashes Reported			
Analysis of Cl	nange With Aggregated Data from A	All Intersections				-2.5	0.006	Increase	

Table 5.5: Change analysis between phase-2 and phase-3, pedestrian crashes.

Intersection	Location	Start Phase 2	End Phase 2	Start Phase 3	End Phase 3	t-statistic	P-value	Change	
1	E Main St & Library Ave	08/03/2010	09/29/2010	09/30/2010	02/29/2012	0.9	0.267	None	
4	E Main St & Pomeroy Lane	03/11/2010	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
9	Delaware Ave & S College Ave	05/04/2010	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
11	Delaware Ave & S Chapel St	06/17/2010	09/29/2010	09/30/2010	02/29/2012	1.0	0.196	None	
14	Delaware Ave & Library Ave	02/12/2009	09/29/2010	09/30/2010	02/29/2012	1.0	0.165	None	
17	Cleveland Ave & N Chapel St	03/10/2010	09/29/2010	09/30/2010	02/29/2012	-1.0	0.166	None	
19	Cleveland Ave & New London Rd	08/03/2010	09/29/2010	09/30/2010	02/29/2012	No Crashes Reported			
22	Elkton Rd & Apple Rd	01/06/2009	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
25	Elkton Rd & Thorn Ln	04/14/2010	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
28	S College Ave & SR 4	10/30/2009	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
29	S College Ave & Marvin Dr	07/08/2010	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
32	S College Ave & E Park Pl	09/24/2009	09/29/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
34	S College Ave & Amstel Ave	07/08/2010	09/29/2010	09/30/2010	02/29/2012	-1.0	0.166	None	
35	Hillside Rd & Apple Rd	03/11/2010	09/29/2010	09/30/2010	02/29/2012	No C	No Crashes Reported		
39	SR 4 & Robscott Manor	09/18/2009	09/29/2010	09/30/2010	02/29/2012	No Crashes Reported			
40	SR 4 & SR 72	02/04/2010	09/29/2010	09/30/2010	02/29/2012	No Crashes Reported			
Analysis of Ch	nalysis of Change With Aggregated Data from All Intersections						0.000	Decrease	

Intersection	Location	Start Phase 1	End Phase 1	Start Phase 3	End Phase 3	t-statistic	P-value	Change	
1	E Main St & Library Ave	01/01/2007	08/02/2010	09/30/2010	02/29/2012	0.2	0.421	None	
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	09/30/2010	02/29/2012	2.1	0.022	Decrease	
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	09/30/2010	02/29/2012	1.0	0.162	None	
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	09/30/2010	02/29/2012	1.0	0.162	None	
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	09/30/2010	02/29/2012	No C	rashes Rep	orted	
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	09/30/2010	02/29/2012	-0.5	0.311	None	
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	09/30/2010	02/29/2012	No C	No Crashes Reported		
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	09/30/2010	02/29/2012	No C	rashes Rep	orted	
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	09/30/2010	02/29/2012	1.0	0.162	None	
28	S College Ave & SR 4	01/01/2007	10/29/2009	09/30/2010	02/29/2012	1.0	0.162	None	
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	09/30/2010	02/29/2012	No C	rashes Rep	orted	
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/30/2010	02/29/2012	1.4	0.086	None	
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	09/30/2010	02/29/2012	0.2	0.421	None	
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	09/30/2010	02/29/2012	No C	No Crashes Reported		
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/30/2010	02/29/2012	No Crashes Reported			
40	SR 4 & SR 72	01/01/2007	02/03/2010	09/30/2010	02/29/2012	No Crashes Reported			
Analysis of Cl	nange With Aggregated Data from A	Analysis of Change With Aggregated Data from All Intersections							

 Table 5.6:
 Change analysis between phase-1 and phase-3, pedestrian crashes.

5.3 Crash Severity, All Crash Types

5.3.1 Crash Severity, All Crash Types, Phase-1 to Phase-2

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The results of this study indicate that there were both significant increases and decreases in crash severity at individual intersections when compared between phase-1 and phase-2.

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Table 5.7:	Change ana	lysis between	phase-1 and	d phase-2,	, crash severity.
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Intersection	Location	Start Phase 1	End Phase 1	Start Phase 2	End Phase 2	t-statistic	P-value	Change
1	E Main St & Library Ave	01/01/2007	08/02/2010	08/03/2010	09/29/2010	-4.3	0.078	None
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	03/11/2010	09/29/2010	2.6	0.007	Decrease
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	05/04/2010	09/29/2010	1.9	0.032	None
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	06/17/2010	09/29/2010	-0.3	0.392	None
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	02/12/2009	09/29/2010	-0.6	0.277	None
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	03/10/2010	09/29/2010	1.0	0.167	None
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	08/03/2010	09/29/2010	3.0	0.002	Decrease
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	01/06/2009	09/29/2010	0.3	0.383	None
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	04/14/2010	09/29/2010	-1.2	0.142	None
28	S College Ave & SR 4	01/01/2007	10/29/2009	10/30/2009	09/29/2010	1.4	0.086	None
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	07/08/2010	09/29/2010	1.4	0.085	None
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/24/2009	09/29/2010	2.3	0.013	Decrease
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	07/08/2010	09/29/2010	2.4	0.011	Decrease
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	03/11/2010	09/29/2010	2.1	0.022	Decrease
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/18/2009	09/29/2010	-1.6	0.068	None
40	SR 4 & SR 72	01/01/2007	02/03/2010	02/04/2010	09/29/2010	0.0	0.500	None
Analysis of Ch	nange With Aggregated Data from A	Il Intersections				-2.1	0.018	Increase

At 5 of 16 intersections there was a significant decrease in severity when MUTCD complaint CPS were installed at intersections where there was not one previously. Using aggregated data to compare phase-1 and phase-2, there was a significant increase in crash severity. The average cost per month, when averaged between all 16 intersections, increased by \$10,765.89. The results of the individual intersections may appear to contradict the results using the aggregated data. An increase or decrease can be statistically insignificant regardless of the amount of increase or decrease if the standard deviation is high. Several of the intersections that did not experience significant decreases had large increases in severity that were not found to be statistically significant. When all of the intersections were averaged, the increases outweighed the decreases. The results of this analysis are shown below in Table 5.7 and more detailed data is provided in Appendix C. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.3.2 Crash Severity, All Crash Types, Phase-2 to Phase-3

The transition from phase-2 to phase-3 experienced significant increase in crash severity when MUTCD compliant CPS were reprogrammed to experimental CPS timing at 3 of 16 intersections.

Intersection	Location	Start Phase 2	End Phase 2	Start Phase 3	End Phase 3	t-statistic	P-value	Change
1	E Main St & Library Ave	08/03/2010	09/29/2010	09/30/2010	02/29/2012	4.6	0.078	None
4	E Main St & Pomeroy Lane	03/11/2010	09/29/2010	09/30/2010	02/29/2012	-1.5	0.076	None
9	Delaware Ave & S College Ave	05/04/2010	09/29/2010	09/30/2010	02/29/2012	-1.1	0.143	None
11	Delaware Ave & S Chapel St	06/17/2010	09/29/2010	09/30/2010	02/29/2012	0.7	0.267	None
14	Delaware Ave & Library Ave	02/12/2009	09/29/2010	09/30/2010	02/29/2012	-0.6	0.277	None
17	Cleveland Ave & N Chapel St	03/10/2010	09/29/2010	09/30/2010	02/29/2012	-0.1	0.461	None
19	Cleveland Ave & New London Rd	08/03/2010	09/29/2010	09/30/2010	02/29/2012	-2.4	0.014	Increase
22	Elkton Rd & Apple Rd	01/06/2009	09/29/2010	09/30/2010	02/29/2012	1.8	0.040	None
25	Elkton Rd & Thorn Ln	04/14/2010	09/29/2010	09/30/2010	02/29/2012	1.3	0.125	None
28	S College Ave & SR 4	10/30/2009	09/29/2010	09/30/2010	02/29/2012	0.1	0.461	None
29	S College Ave & Marvin Dr	07/08/2010	09/29/2010	09/30/2010	02/29/2012	0.5	0.315	None
32	S College Ave & E Park Pl	09/24/2009	09/29/2010	09/30/2010	02/29/2012	-2.1	0.024	Increase
34	S College Ave & Amstel Ave	07/08/2010	09/29/2010	09/30/2010	02/29/2012	-2.1	0.025	Increase
35	Hillside Rd & Apple Rd	03/11/2010	09/29/2010	09/30/2010	02/29/2012	-1.0	0.166	None
39	SR 4 & Robscott Manor	09/18/2009	09/29/2010	09/30/2010	02/29/2012	1.9	0.042	None
40	SR 4 & SR 72	02/04/2010	09/29/2010	09/30/2010	02/29/2012	0.5	0.315	None
Analysis of Cl	hange With Aggregated Data from A	Il Intersections	•			4.0	0.000	Decrease

Table 5.8: Change analysis between phase-2 and phase-3, crash severity.

Interestingly, the same intersections that experienced change in severity between phase-2 and phase-3 also had significant change between phase-1 and phase-2. However, the transition to experimental CPS timing saw an increase in severity where as the initial installation of CPS saw a decrease in severity. Using aggregated data to compare phase-2 and phase-3, there was a significant decrease in crash severity. The average cost per month, when averaged between all 16 intersections, decreased by \$20,532.66. The results of this analysis are shown below in Table 5.8 and more detailed data is provided in Appendix C. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.3.3 Crash Severity, All Crash Types, Phase-1 to Phase-3

This study compared the change in crash severity between phase-1 and phase-3. This transition is equivalent to installing a CPS with experimental timing at an intersection where there was not a CPS previously.

Intersection	Location	Start Phase 1	End Phase 1	Start Phase 3	End Phase 3	t-statistic	P-value	Change
1	E Main St & Library Ave	01/01/2007	08/02/2010	09/30/2010	02/29/2012	0.9	0.187	None
4	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	09/30/2010	02/29/2012	0.2	0.421	None
9	Delaware Ave & S College Ave	01/01/2007	05/03/2010	09/30/2010	02/29/2012	0.4	0.346	None
11	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	09/30/2010	02/29/2012	1.4	0.083	None
14	Delaware Ave & Library Ave	01/01/2007	02/11/2009	09/30/2010	02/29/2012	-1.0	0.164	None
17	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	09/30/2010	02/29/2012	1.0	0.162	None
19	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	09/30/2010	02/29/2012	0.6	0.276	None
22	Elkton Rd & Apple Rd	01/01/2007	01/05/2009	09/30/2010	02/29/2012	1.9	0.033	None
25	Elkton Rd & Thorn Ln	01/01/2007	04/13/2010	09/30/2010	02/29/2012	0.7	0.244	None
28	S College Ave & SR 4	01/01/2007	10/29/2009	09/30/2010	02/29/2012	1.5	0.071	None
29	S College Ave & Marvin Dr	01/01/2007	07/07/2010	09/30/2010	02/29/2012	1.6	0.059	None
32	S College Ave & E Park Pl	01/01/2007	09/23/2009	09/30/2010	02/29/2012	-0.7	0.245	None
34	S College Ave & Amstel Ave	01/01/2007	07/07/2010	09/30/2010	02/29/2012	-0.8	0.216	None
35	Hillside Rd & Apple Rd	01/01/2007	03/10/2010	09/30/2010	02/29/2012	0.8	0.214	None
39	SR 4 & Robscott Manor	01/01/2007	09/17/2009	09/30/2010	02/29/2012	1.0	0.162	None
40	SR 4 & SR 72	01/01/2007	02/03/2010	09/30/2010	02/29/2012	0.5	0.310	None
Analysis of Ch	nange With Aggregated Data from A	Il Intersections				2.2	0.014	Decrease

Table 5.9: Change analysis between phase-1 and phase-3, crash severity.

None of the 16 study intersections experienced significant change. However, Using aggregated data to compare phase-1 and phase-3, there was a significant

decrease in severity. The average cost per month, when averaged between all 16 intersections, decreased by \$9,766.77. The results of this analysis are shown below in Table 5.9 and more detailed data is provided in Appendix C. A P-value of less than 0.025 is considered significant at a 95% confidence interval.

5.4 Intersections That Experienced Change

Seven of sixteen intersections displayed significant change in some way throughout the study. The remaining nine had no change during any phase. CPS installation or signal timing modification effected crash frequency or crash severity at the following intersections:

- E Main St & Pomeroy Lane
- Cleveland Ave & New London Rd
- Elkton Rd & Apple Rd
- S College Ave & E Park Pl
- S College Ave & Amstel Ave
- Hillside Rd & Apple Rd
- SR 4 & SR 72

There is nothing apparently unique about these intersections that resulted in their experiencing change. Without vehicle or pedestrian volumes it is not possible to determine if these volumes or pedestrian exposure affected the results. Appendix D summarizes the significant change and highlights the change at these seven intersections.

Chapter 6

DISCUSSION

This chapter will expand on the results of the study and present arguments about their significance. The results will also be discussed alongside previous studies that were presented in the literature review to help determine how this research should be understood. Additional discussion will also be directed at how this research should be considered by policy makers and what effect it has on the transportation network and the safety of all road users. This study presented several questions that should be addressed individually:

- 1. Does the installation of CPS at a signalized intersection affect crash frequency or severity?
- 2. Are intersections with CPS that count down to zero at the beginning of yellow more or less safe than CPS that countdown to zero at the beginning of red?
- 3. How do these results impact the application of CPS at signalized intersections?
- 4. Should changes be made to the federal and/or state regulations for CPS installation?

6.1 Effect of Installing a Countdown Pedestrian Signal

The initial installation of CPS with countdown to yellow did not increase crash frequency or severity at any individual intersection. However, crash frequency was reduced at four intersections, pedestrian crash frequency was reduced at one intersection, and crash severity was reduced at five intersections. By looking at the individual intersection data, it would appear that intersection safety was improved with the installation of CPS. These results, paired with the results of the pedestrian observation study at the same sixteen study intersections [3], confirms this observation. These results are consistent with the conclusions of three other studies [5, 6, 8] that studied crash frequency in 'before and after' studies of CPS installation. However, these results are not conclusive in proving that there was a significant and substantial improvement in intersection safety for two reasons. First, the results of the analyses using aggregated data conflicted with results obtained when analyzing the intersections individually. It is noteworthy that crash severity and pedestrian crash frequency increased, on average, with the installation of CPS with countdown to yellow. Second, seven of ten significant changes between phase-1 and phase-2 should be discounted because phase-2 was too short to gain accurate results. The remaining three of ten significant changes at the intersections of E Main St & E Pomeroy Ln and S College Ave & E Park Pl, should be considered as significant based on length of phase-2 and number of reported crashes. Further research is needed to gain more conclusive results about the impact of installing CPS with countdown synchronized with the beginning of the concurrent vehicular yellow indication.

6.2 Study Area Crash Frequency, 2007–2012

The total number of crashes per month that occurred at all intersections throughout this study remained relatively constant (Figure 6.1). Sharp variations between months, as seen in this data, are typical for crash data. This can be viewed as a sample of crash frequency in the Newark area and is a good indication of the regional trend in crash activity. The slope of the trend line for five years of crash data

is close to zero. This also shows that there were no dramatic changes in crash frequency as a result of introducing CPS or changing their signal timing.



Figure 6.1: Total crashes per month at sixteen study intersections

6.3 Effect of Changing Countdown Pedestrian Signal Timing

Results varied by intersection when signal timing was changed from 'countdown to yellow' to 'countdown to red'. Crash frequency decreased at one intersection and increased at two intersections. Crash severity increased at three intersections. On average, using aggregated data, crash frequency of all types of crashes did not change, and crash severity, jaywalking, and pedestrian crash frequency decreased with the installation of CPS with 'countdown to red'. These results can be difficult to interpret because, on average, the intersections became safer when the 'countdown to red' was introduced. However, there were three intersections where there were significant increases in crash frequency and crash severity. There are no other studies that have been published evaluating these signal timings, so it is not possible to compare these results with other studies. It is worth taking a closer look at the individual intersections. Two of the three intersections that experiencing significant change should be discounted because of limited data. The intersection of Cleveland Ave & New London Rd had no crashes in phase-2, and phase-2 was 2 months long. So naturally with any typical crash rate, phase-3, which was 17 months long, would result in a significant increase in crash severity. The intersection of S College Ave & Amstel Ave is similar, with phase-2 covering 3 months. There is one intersection that seems to have experienced significant increase in severity – that is, S College Ave & E Park Pl. At this intersection, all study phases were sufficiently long and crash frequencies were great enough to gain an accurate indication of change in crash severity. These results suggest that the severity analysis may indicate that the 'countdown to red' may create safer traffic control for the greater population. It is noteworthy that the economic impact of crashes at an average intersection when the CPS counted down to red (phase-3) was \$20,532.66 less per month than when CPS counted down to yellow (phase-2). Additionally, the economic impact when the CPS counted down to red (phase-3) was \$9,766.77 less per months than intersections that did not have a CPS installed (phase-1).

6.4 Evaluation of Experimental Signal Timing

Special attention should be given to the comparison between phase-1 and phase-3 because it relates to the primary objective of this study – that is, Is there a safety concern with allowing pedestrian countdown signals to terminate (reach zero) at the end of the concurrent vehicular yellow phase? This transition is equivalent to installing a CPS with 'countdown to red' at an intersection with no CPS. First, looking

at the aggregated data, there was no change in crash frequency, there was a decrease in pedestrian crash frequency, and there was a decrease in crash severity. This indicates that, on average, installing CPS with the experimental timing makes intersections more safe than before installation and does not present a safety concern. Second, looking at the individual intersections provides a different interpretation. Significant change was observed in 3 of 48 (6%) comparisons in this transition (48 comparisons consists of the three methods of analysis at 16 intersections). At one intersection there was a drastic increase in crash frequency and at a second intersection there was an even larger decrease in crash frequency. At the intersection of E Main St & Pomeroy Ln there was a decrease in pedestrian crashs reported. More in-depth analysis is needed to understand the cause of this change and how it was related to pedestrian and driver behavior and signal response. These results indicate that there is not a safety concern with allowing pedestrian countdown signals to terminate (reach zero) at the end of the concurrent vehicular yellow phase.

6.5 Mapping the Results

These results are complex since change was reported at different intersections in different ways. It is helpful to view these results in a spatial context. Figure 6.2 presents the results on a map with a table for each intersection that experienced any change. Each table displays the change between each of the three study phases as well as each of the three methods of analysis. Each of the sixteen study intersections is marked on the map by a circle. The diameter of the circle represents the average severity of a single crash incident at each intersection. This value of severity is calculated by summing the total economic impact of all crashes at a single

intersection, divided by the total number of crashes in this five-year study. This does not affect the results, but is an interesting observation from conducting this analysis. The individual value of severity at each intersection is also detailed in Figure 6.3 below. Intersections are arranged in order of severity of an average crash incident.



Figure 6.2: Average crash severity and significant change



Figure 6.3: Average severity of a crash at each intersection (in order of severity)

The distribution of crash classification at a particular intersection directly influence the average cost per month calculated in the crash severity analysis. One way to look at the crash data is to see if the changes in CPS timing effected this distribution, in effect making the crashes more or less severe. All crashes in the study were grouped by classification and phase. The percentage of total crashes that resulted in a fatality, personal injury, or property-damage-only was calculated for each phase (Table 6.1).

 Table 6.1:
 Distribution of crash classification between phases

Crash Classification	Phase 1	Phase 2	Phase 3
Property Damage Only	70.0%	66.5%	71.0%
Personal Injury	29.9%	33.5%	29.0%
Fatality	0.2%	0.0%	0.0%

The distribution of crash severity was roughly the same in phase-1 and phase-3; confirming that there was no change in distribution of crash classification when the experimental timing was used. In phase-2 there was a 3.6 percent increase in the percentage of crashes that were personal injury crashes as compared to phase-1. This aligns with the significant increase in crash severity that was observed when statistical analyses were conducted using aggregated data.

6.6 Evaluation of Data and Analysis

When viewing the results concerning severity, it is important to note that personal injury crashes are all counted uniformly, there is no distinction in this study between a minor and a major injury. This distinction is provided in the crash records, but is seen as unreliable because it is based on the evaluation of the reporting officer and not those of a medical professional after the crash event. According to a study on the accuracy of police reported injury severity, 49% of injuries coded as incapacitating injuries were actually no more than minor injuries [14]. So in the case of personal injury crashes in this study, a bruise is counted the same way as a life threatening injury. This has an effect on the crash severity analysis and could have skewed the results in the direction of increased severity.

Using a 95% confidence interval (CI) with an alpha value of 0.025 increases the risk of type-I and type-II statistical errors. A type-I error would occur if significant change were calculated when there actually was no change. A type-II error would occur if there were not a significant change calculated when there actually was significant change. These errors can lead to false conclusions and researchers missing a real impact within their study. In this study, there could be a real impact to safety that was missed as a result of the tight CI.

As a test for these errors, the analysis was screened for change at a 90% CI using an alpha value of 0.05. Using this CI, there were additional intersections that displayed change. The intersection of Delaware Ave & S College Ave had a significant decrease in severity between phase-1 and phase-2. The intersection of SR 4 & Robscott Manor had a significant decrease in severity between phase-2 and phase-3. Additionally, three intersections that displayed change at a 95% CI showed additional change at the 90% CI. Elkton Rd & Apple Rd had a significant decrease in severity between phase-2 and phas-3 and between phase-1 and phase-3. The intersection of S College Ave & E Park Pl had a significant increase in crash frequency between phase-2 and phase-3. The intersection of S College Ave & Amstel Ave had a significant decrease in pedestrian crash severity between phase-1 and phase-2. In total, at the 90% CI there were 31 changes observed at 56% of the study intersections. At the 95% CI there were 25 total changes observed at 44% of the study intersections. These results will not be accounted for in the analysis or conclusions of this study and are only shown here for a demonstration of the constraints of the 95% CI that was selected for this study. There does not appear to be any major statistical errors of type-I or type-II that would change the conclusions of this research.

6.7 Impacts and Recommendations

This study verified that no additional hazard was introduced when the synchronization was changed from yellow to red. This confirms the conclusion of the pedestrian behavior observational study. The crash analysis study, as compared to the observational study, had the benefit of a longer time frame to study the effects of changing the CPS synchronization. The observational study was limited to vehicle-pedestrian conflicts and pedestrian behavior during a few hours. This was a limited

scope for testing the indirect impacts of installing a CPS and changing synchronization. The crash analysis was able to test for these impacts in a broader scope. The crash analysis did not show a substantial change in crash frequency or severity, so it is not appropriate to recommend that changes be made to the existing standards for CPS installation and operation. The positive effects of CPS have been tested and confirmed in multiple studies in different regions and countries. The published research on CPS shows that in some situations they cause a dramatic reduction in crashes and in other situations there is no significant change. This research aligns with studies that resulted in no significant change in crash frequency. Beyond the lack of change in crash frequency, this study observed significant decreases in crash severity with the installation of CPS with both alternatives for countdown synchronization (to yellow and to red).

Based on the results of this research, we do not recommend any changes to federal or state regulations for the installation of CPS based on the results of this research. This research verified that there is no significant impact on intersection safety between the optional CPS timing scenarios represented by phase-2 and phase-3 of this study.

Chapter 7

CONCLUSIONS

Crash records were quantitatively evaluated to determine if there was a significant change in crash frequency, pedestrian crash frequency, and crash severity between three variations in CPS timing. Five years of crash records from sixteen intersections were used in this analysis. Signal timings varied between no-CPS, CPS with countdown terminating at the beginning of yellow, and CPS with countdown terminating at the beginning of red.

Results showed that there was not a significant change (with 95% confidence interval) in crash frequency between each variation in CPS timing.

This study verified that no additional hazard was introduced when the synchronization was changed from yellow to red. There was no change in distribution of crash classification when the experimental timing was used.

The economic impact of crashes at an average intersection when the CPS counted down to red was less per month than when CPS counted down to yellow. Additionally, the economic impact when the CPS counted down to red was less per months than intersections that did not have a CPS installed.

Based on the results of this research, no changes are recommended to federal or state regulations for the installation of CPS. Further research is needed to determine if changes to the existing standards would improve safety. Ideas for further research on CPS and recommendations for improving data quality are included in chapter 8.

Chapter 8

FUTURE WORK

In the process of conducting this research, additional data and tangential projects were identified that would be complementary to this study and advance our understanding of this public safety issue.

8.1 Additional Data

After conducting this study, it is apparent that additional data would enhance this study and enable a more detailed analysis of the causes of change in crash frequency and crash severity at individual intersections. By including vehicular volumes and pedestrian volumes it would be possible to calculate crash rates for each intersection per phase. Crash rate is a calculation that includes the number of crashes, the length of time studied, and the vehicular volumes of both cross streets. Crash rate is typically presented in crashes per million vehicles entering an intersection. Once a crash rate was calculated, each intersection could be compared with the statewide average for similar types of intersections. The pedestrian volumes would be used in calculating exposure at each intersection in a similar manner to the vehicular crash rate. From this, conclusions could be drawn as to how CPS effects high and low volume intersections. It would be preferable to collect both vehicular and pedestrian data using an automatic traffic recorder (ATR) so that the true average daily traffic is known and any fluctuations in seasonal volumes are accounted for. Newark, Delaware is a college town and there are significant fluctuations in pedestrian traffic throughout the year. This data is expensive and was not included in the budget for this research.

8.2 Larger Sample

Future research on this topic should include longer study periods in 'before and after' type studies. It would be preferential to have over 30 months of data to conduct an accurate analysis. The longer periods would provide a better picture of the actual population distribution. When using smaller sample sizes, assumptions have to be made about the distribution of sample data.

It would also be preferential to collect crash data for two years before and after the study to look at the larger trend in crash frequency. As discussed in the literature review, regression to the mean can be misinterpreted as significant change. It is not possible to compare crashes at an intersection with changes traffic signals with a 'control', no-change intersection, since each intersection is unique in the many factors influencing crash frequency.

8.3 Crash Type Analysis

Looking at changes in distribution of crash types between phases would supplement the severity analysis considering the potential error in police-reported injury severity. This analysis is possible with the available data but was not done because of time constraints.

8.4 Crash Severity Analysis

An alternative calculation of change in crash severity could be conducted. Calculations would be done in a way that uses each crash incident as a sample that contrasts from the way this study was conducted. The focus would be on measuring the change in severity of each crash event between phases. The current analysis takes average cost per month per phase at each intersection. The proposed analysis would take the average cost per incident per phase per intersection. The current analysis was chosen to mirror the crash frequency calculations.

8.5 Spatial Analysis of Crash Severity

The local Metropolitan Planning Organization (MPO), WILMAPCO, has used geographic information systems (GIS) to plot the locations of crashes in New Castle County, Delaware. The intersections are categorized and sorted by roadway functional classification of the intersecting streets. Through this analysis, it is possible to locate abnormally high crash frequencies or 'crash hot-spots'. A similar analysis could be conducted by plotting the severity of an average crash incident using GIS (similar to figure 6.2). This study should be conducted over a large area with multiple intersections, such as New Castle County.

8.6 Novelty Effect

It is possible that some of the change experienced in phase-2 of this study was connected with drivers learning how to react to a new traffic control device. When phase-3 was studied the CPS had been in operation for several months. An additional set of crash data could be collected following phase-3. The new data could be compared with the existing phase-2 data to see if there was any novelty effect. Another method to reduce this effect would be to remove the first month of data from each phase. At the end of the first month of operation, it could be expected that local drivers would 'learn' and therefore be familiar with a new device or changes in signal timing.

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Appendix A

DATA AND ANALYSIS OF CRASH FREQUENCY

		Analysis of Change With Aggregated Data from All Intersections			590	656	1.13	1.05			130	158	1.17	0.88			272	293	1.08	0.90	-0.04	-0.47	217.92	0.509 None		0.10	1.04	259.58	0.16	None	0.07	0.00	607.17	0.212	None
40	N346	2L אS ጭ ቱ אS	01/01/2007	02/03/2010	37	100	2.70	1.91	02/04/2010	09/29/2010	8	29	3.63	1.60	09/30/2010	02/29/2012	17	81	4.76	2.19	-0.92	-1.43	11.79	0.095 None	AllONT	-1.14	-1.47	18.55	0.08	None	202	00.7-		0.001	Increase
39	N241	70 4 & Robscott Manor	01/01/2007	09/17/2009	33	∞	0.24	0.56	09/18/2009	09/29/2010	12	5	0.42	0.51	09/30/2010	02/29/2012	17		0.18	0.39	-0.17	-0.98	21.18	0.164 Nona	NION	0.24	1.36	19.62	0.09	None	0.07	0.07	43.33	0.310	None
35	N663T	bA əlqqA & bA əbislliH	01/01/2007	03/10/2010	38	7	0.18	0.39	03/11/2010	09/29/2010	7	0	0.00	0.00	09/30/2010	02/29/2012	17	2	0.12	0.49	0.18	2.89	37.00	0.005	A00A10A7	-0.12	-1.00	16.00	0.17	None	20.07	0.0/	00 25.81	0.311	None
34	N448T	əvA ləîzmA & əvA əgəlloO 2	01/01/2007	07/07/2010	42	8	0.19	0.40	01/08/2010	09/29/2010	3	0	0.00	0.00	09/30/2010	02/29/2012	17	5	0.29	0.47	0.19	3.11	41.00	Doctono	DVII VIII VIII	-0.29	-2.58	16.00	0.01	Increase	010	01.0-	75 77	0.215	None
32	N438T	S College Ave & E Park Pl	01/01/2007	09/23/2009	33	28	0.85	0.91	09/24/2009	09/29/2010	12	4	0.33	0.65	09/30/2010	02/29/2012	17	13	0.76	0.66	0.52	2.10	27.27	0.023	1001100	-0.43	-1.74	24.14	0.05	None	0.00	0.08	42.04	0.346	None
29	N467T	S College Ave & Marvin Dr	01/01/2007	07/07/2010	42	15	0.36	0.66	07/08/2010	09/29/2010	3	3	1.00	1.00	09/30/2010	02/29/2012	17	9	0.18	0.39	-0.64	-1.10	2.12	0.195 None	ATIONT	0.82	1.41	2.11	0.15	None	010	0.18	48.41	0.101	None
28	N436	ት Я2 ŵ sve & SR 4	01/01/2007	10/29/2009	34	101	2.97	1.80	10/30/2009	09/29/2010	11	25	2.27	1.56	09/30/2010	02/29/2012	17	37	2.18	1.74	0.70	1.24	19.45	0.122 Nona		0.10	0.15	23.24	0.42	None	0.40	67.0	11 22	0.071	None
25	N411T	nJ modT & bA nobl3	01/01/2007	04/13/2010	39	12	0.31	0.47	04/14/2010	09/29/2010	6	2	0.33	0.52	09/30/2010	02/29/2012	17		0.18	0.39	-0.03	-0.11	6.33	0.462 Nona	ATION	0.16	0.68	7.16	0.25	None	610	0.13	36.06	0.139	None
22	N414T	bЯ siqqA & bЯ nob∐∃	01/01/2007	01/05/2009	24	25	1.04	1.40	01/06/2009	09/29/2010	21	27	1.29	1.23	09/30/2010	02/29/2012	17	5	0.29	0.59	-0.24	-0.62	43.00	0.2/0 None	AllONT	0.99	3.26	29.90	0.00	Decrease	0.75	c/.0	40.05	0.014	Decrease
19	N439T	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	43	29	0.67	0.92	08/03/2010	09/29/2010	2	0	0.00	0.00	09/30/2010	02/29/2012	17	8	0.47	0.62	0.67	4.81	42.00	Decreases	PV414404	-0.47	-3.11	16.00	0.00	Increase	000	07:0	43.00	0.162	None
17	N431T	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	38	64	1.68	1.36	03/10/2010	09/29/2010	7	6	1.29	0.76	09/30/2010	02/29/2012	17	23	1.35	1.06	0.40	1.10	14.42	0.144 Mona	AllONT	-0.07	-0.18	15.73	0.42	None		0.05	30.12	0.162	None
14	N424T	Delaware Ave & Library Ave	01/01/2007	02/11/2009	25	46	1.84	1.40	02/12/2009	09/29/2010	20	37	1.85	1.50	09/30/2010	02/29/2012	17	33	1.94	1.71	-0.01	-0.02	39.64	002.0 None		-0.09	-0.17	32.11	0.42	None	010	-0.10	20.8.0	0.421	None
11	N430T	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	41	30	0.73	1.03	06/17/2010	09/29/2010	4	1	0.25	0.50	09/30/2010	02/29/2012	17	=	0.65	0.70	0.48	1.62	5.89	0.080 Mono		-0.40	-1.31	6.18	0.12	None	0.00	0.08	43.28	0.346	None
6	N428T	Delawate Ave & S College Ave	01/01/2007	05/03/2010	40	28	0.70	0.79	02/04/2010	09/29/2010	5	5	1.00	1.00	09/30/2010	02/29/2012	17	8	0.47	0.62	-0.30	-0.65	4.65	0.28/ Mona	ATAX	0.53	1.12	4.95	0.16	None		27.1	38.02	0.119	None
4	N714T	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	38	15	0.39	0.59	03/11/2010	09/29/2010	7	1	0.14	0.38	09/30/2010	02/29/2012	17	5	0.29	0.59	0.25	1.46	12.30	0.080 None		-0.15	-0.75	17.42	0.25	None	010	01.0	31.17	0.277	None
1	N423T	9vA yurdi J & IZ maM H	01/01/2007	08/02/2010	43	140	3.26	2.15	08/03/2010	09/29/2010	2	10	5.00	2.83	09/30/2010	02/29/2012	17	53	3.12	1.73	-1.74	-0.86	1.05	0.26/ Nona	ATTAL	1.88	0.92	1.09	0.27	None		0.14	36.30	0.383	None
Intersection Number	Signal Permit No.	Intersection Location	Start Date Phase 1	End Date Phase 1	Months Sampled in Phase 1	Crashes Reported in Phase 1	Average Crashes per Month	Standard Deviation of Crashes per Month	Start Date Phase 2	End Date Phase 2	Months Sampled in Phase 2	Crashes Reported in Phase 2	Average Crashes per Month	Standard Deviation of Crashes per Month	Start Date Phase 3	End Date Phase 3	Months Sampled in Phase 3	Crashes Reported in Phase 3	Average Crashes per Month	Standard Deviation of Crashes per Month	Difference of Averages	t-statistic	v Degrees of Freedom	P-value Significant Change (95% CT)	Digunicant Change (22/9 Ct)	Difference of Averages	t-statistic	v Degrees of Freedom	P-value	Significant Change (95% CI)	N100	Difference of Averages	v Degrees of Freedom	P-value	Significant Change (95% CI)
			s Â:	àqų iene ata	L 4 nbə. C I	ase- 17 17 18 19 19 19 19 19 19 19 19 19 19 19 19 19	UII C Lust Lust	v O	s Â	ype ata afta	. Ц nbə. С 7 [.]	ase- h Fi 2813) se. :44	v v	sa Áo	ats nen Oats	L US Ibə. I E-	ase T fi) IIV SB.1; YA	́о		56 12 01 14 01 14 01	ueų sáje seų, -əsei) IV 4 14			56 is o 5-3 7 f0	ueu sáp seu -əsi	CI Buy Id BP ¹	,		to F of	1-98 -926 Sisy Sng	U P P P P P P P P P	r

Appendix B

DATA AND ANALYSIS OF PEDESTRIAN CRASH FREQUENCY

		Analysis of Change With Aggregated Data from All Intersections			590	17	0.03	0.12			130	3	0.05	0.09			272	3	0.01	0.05	0.00		238.26	0.006	Increase	0.04	4.69	161.69	0.000	Decrease	0.02	-0.0	840.98	0.002	Decrease
40	N346	7L NS % + NS	01/01/2007	02/03/2010	37	0	0.00	0.00	0100/10/00	09/29/2010	∞	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	0.00	No Crashes	Reported		0.00		No Crashes	Reported		000	0.0	No Cenchas	Reported	
39	N241	SR 4 & Robscott Manor	01/01/2007	09/17/2009	33	0	0.00	0.00	00/0/81/00	09/29/2010	12	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	0000	No Crashes	Reported		0.00		No Crashes	Reported		000	0.00	No Conchas	Reported	,
35	N663T	bA əlqqA & bA əbisliiH	01/01/2007	03/10/2010	38	0	0.00	0.00	03/11/2010	09/29/2010	7	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	00.0	No Crashes	Reported		0.00		No Crashes	Reported		000	00.0	No Cushas	Reported	,
34	N448T	ovA lotzmA & ovA sgolloD S	01/01/2007	07/07/2010	42	3	0.07	0.26	0100/30/20	09/29/2010	3	0	0.00	0.00	09/30/2010	02/29/2012	17	1	0.06	0.24	0.07	1 70	41.00	0.040	None	-0.06	-1.00	16.00	0.166	None	100	010	31.75	0.421	None
32	N438T	S College Ave & E Park Pl	01/01/2007	09/23/2009	33	2	0.06	0.24	00/07/70/00	09/29/2010	12	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	0.06	1 44	32.00	0.086	None	0.00		No Crashes	Reported		0.06	1 44	32.00	0.086	None
29	N467T	S College Ave & Marvin Dr	01/01/2007	07/07/2010	42	0	0.00	0.00	0100/30/20	09/29/2010	6	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	0.00	No Crashes	Reported		0.00		No Crashes	Reported		000	0.0	No Cuschas	Reported	
28	N436	S College Ave & SR 4	01/01/2007	10/29/2009	34	1	0.03	0.17	0000/02/01	09/29/2010	11	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	0.02	0.01	33.00	0.162	None	0.00		No Crashes	Reported		0.02	001	33.00	0.162	None
25	N411T	nJ modT & A for La	01/01/2007	04/13/2010	39	-	0.03	0.16	0106/01/00	09/29/2010	9	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	0.02	1 00	38.00	0.162	None	0.00		No Crashes	Reported		0.02	001	38.00	0.162	None
22	N414T	bA əlqqA & bA noralƏ	01/01/2007	01/05/2009	24	0	0.00	0.00	0000/20/10	09/29/2010	21	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	0.00	No Crashes	Reported		0.00		No Crashes	Reported		000	00.0	No Cuschas	Reported	
19	N439T	Cleveland Ave & New London Rd	01/01/2007	08/02/2010	43	0	0.00	0.00	0100/20/80	09/29/2010	2	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	000	0.00	No Crashes	Reported		0.00		No Crashes	Reported		000	0.00	No Coolean	Reported	,
17	N431T	Cleveland Ave & N Chapel St	01/01/2007	03/09/2010	38	-	0.03	0.16	03/10/2010	09/29/2010	7	0	0.00	0.00	09/30/2010	02/29/2012	17	1	0.06	0.24	0.02	00.0	37.00	0.162	None	-0.06	-1.00	16.00	0.166	None	-0.02	050	39.00	0.311	None
14	N424T	Delaware Ave & Library Ave	01/01/2007	02/11/2009	25	0	0.00	0.00	0000/01/00	09/29/2010	20	1	0.05	0.22	09/30/2010	02/29/2012	17	0	0.00	0.00	0.05	1 00	19.00	0.165	None	0.05	1.00	19.00	0.165	None	000	0.0	No Curchae	Reported	
11	N430T	Delaware Ave & S Chapel St	01/01/2007	06/16/2010	41	1	0.02	0.16	0100/21/90	09/29/2010	4	1	0.25	0.50	09/30/2010	02/29/2012	17	0	0.00	0.00	0.72	0000	3.06	0.217	None	0.25	1.00	3.00	0.196	None	0.00	1 00	40.00	0.162	None
6	N428T	ovA ogollo Z	01/01/2007	05/03/2010	40	-	0.03	0.16	0100/10/20	09/29/2010	5	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	0.02	001	39.00	0.162	None	0.00	4	No Crashes	Reported		0.02	001	30.00	0.162	None
4	N714T	E Main St & Pomeroy Lane	01/01/2007	03/10/2010	38	4	0.11	0.31	0100/11/20	09/29/2010	7	0	0.00	0.00	09/30/2010	02/29/2012	17	0	0.00	0.00	110	000	37.00	0.022	Decrease	0.00		No Crashes	Reported		110	000	27.00	0.022	Decrease
1	N423T	9vA yurdi L & I & ninM H	01/01/2007	08/02/2010	43	9	0.07	0.26	0100/20/80	09/29/2010	2	1	0.50	0.71	09/30/2010	02/29/2012	17	1	0.06	0.24	0.42	20.0	-0.00	0.267	None	0.44	0.88	1.03	0.267	None	0.01	0.15	112	0.421	None
Intersection Number	Signal Permit No.	lutersection Location	Start Date Phase 1	End Date Phase 1	E S Months Sampled in Phase 1	E 2 2 Crashes Reported in Phase 1	a C Average Crashes per Month	C Standard Deviation of Crashes per Month	Citate Data Diraca 3	E E End Date Phase 2	GE O Months Sampled in Phase 2	도 등 등 Crashes Reported in Phase 2	a C T Average Crashes per Month	C Standard Deviation of Crashes per Month	E. Start Date Phase 3	트 프 트 End Date Phase 3	문 글 🖉 Months Sampled in Phase 3	도 등 품 Crashes Reported in Phase 3	풀 주 문 Average Crashes per Month	C Standard Deviation of Crashes per Month	Differences of Arona cos	of the second seco	as sistent of the second of th	Ph as C P-value	Significant Change (95% CI)	Difference of Averages	e-is to t-statistic	a 2 2 a v Degrees of Freedom	P = O P-value	Significant Change (95% CI)	Difference of Arometee	of the state of th	Value of Provident	Participation of the second se	Significant Change (95% CI)
			[ete	a ı	-əsi	еча	5		e te	a 7	-əsi	ча			ete(1 6.	-əse	Чd	1		03	1-98	вча		¢	n 7.	əst	.च पत			03	1-9	sed.	ε

Appendix C

DATA AND ANALYSIS OF ACCIDENT SEVERITY

-	Intersection Number	-	4	6	=	4	17	19	22	25	28	29	32	34	35	39	66	
-	Signal Permit No.	N423T	N714T	N428T	N430T	N424T	N431T	N439T	N414T	N411T	N436	N467T	N438T	N448T	N663T	N241	N346	
	ntessection Location	e Main St & Library Ave	ans. I conservy Lane	Delaware Ave & S College Ave	Delaware Ave & S Chapel St	Delaware Аче & Library Аче	12 ləqad V & svA bnaləvəD	DA nobno.l woN & ovA bunlovoD	bA əlqq∆ & bA nobl∃	a.I avod T & bS avod I.I	4 A2 & 94A 929IIOD S	TG nivraM & vv6 s2910O S	I Алга Э У У Солевания С	əvA ləizmA & əvA əgəlloD Z	bA əlqqA & bA əbizlliH	SK 4 & Robscott Manor	7L ዝS ຈີ † ዝS	Analysis of Change With Aggregated Data from All Intersections
s	Mart Date Phase 1	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	01/01/2007	
ype yrity afa	End Date Phase 1	08/02/2010	03/10/2010	05/03/2010	06/16/2010	02/11/2009	03/09/2010	08/02/2010	01/05/2009	04/13/2010	10/29/2009	07/07/2010	09/23/2009	07/07/2010	03/10/2010	09/17/2009	02/03/2010	
Т Ч элэ С І	Months Sampled in Phase	43	38	40	41	25	38	43	24	39	34	42	33	42	38	33	37	590
se.i S 4º -əsi	Crashes Reported in Phase	140	15	28	30	46	64	29	25	12	101	15	28	8	7	~	100	656
П С уляа БРа	Average Cost per month	\$119,783.72	\$16,652.63	\$25,965.00	\$29,392.68	\$80,176.00	\$49,013.16	\$34,923.26	\$70,891.67	\$10,171.79	\$113,638.24	\$30,057.14	\$33,306.06	\$8,361.90	\$11,073.68	\$4,315.15	\$115,975.68	S47,106.11
v	Standard Deviation of Cost per Month	\$113,161.80	\$36,363.56	\$50,656.66	\$58,910.73	\$83,563.11	\$67,514.23	\$75,408.76	\$105,615.94	\$29,470.66	\$114,741.87	\$92,113.43	\$46,674.22	\$22,974.78	\$32,013.34	\$15,331.53	\$256,309.42	\$75,051.50
Si A	Start Date Phase 2	08/03/2010	03/11/2010	05/04/2010	06/17/2010	02/12/2009	03/10/2010	08/03/2010	01/06/2009	04/14/2010	10/30/2009	07/08/2010	09/24/2009	07/08/2010	03/11/2010	09/18/2009	02/04/2010	
ete Tiri Ype	End Date Phase 2	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	09/29/2010	
LЧ элэ С 7	Months Sampled in Phase	2	7	5	4	20	7	2	21	9	=	9	12	3	7	12	~	130
se. S 4 -əs	Crashes Reported in Phase	10	-	5	_	37	6	0	27	2	25	3	4	0	0	5	29	158
L C L S L S L S L S L S L S L S L S L S L S	Average Cost ner month	\$407.150.00	\$1.300.00	\$9.100.00	\$39.350.00	\$100.060.00	\$31,585.71	\$0.00	\$63.580.95	\$39.350.00	\$72.954.55	\$9,100.00	\$8.833.33	\$0.00	S0.00	\$27,750.00	\$115.837.50	\$57.872.00
IV D I	tandard Daviation of Cost nor Month	\$07 350 00	\$3 184 34	\$2 120 70	668 156 20	00 097 9213	625 884 74	\$0.00	C78 608 AD	\$60.108.12	C70 102 54	67 430 12	C24 045 37	00.00	\$0.00	£48 370 58	19 475 2013	CA6 708 07
	Standard Deviation of Cost per stout	00.000,200	101100	C7-CC1'00	071001000	00.001,0216	17-100-000	00.00	01-0201010	71.001,000	L	71.001.10	7010106170	00.00	00.06	00.000000	10.7710	76:061 0000
1	itart Date Phase 3	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010 (09/30/2010	09/30/2010	09/30/2010	09/30/2010	09/30/2010	
ity ity ity	Ind Date Phase 3	02/29/2012	01/06/00	02/29/2012	01/06/00	02/29/2012	00/06/00	02/29/2012	01/06/00	02/29/2012	02/20/2012	01/06/00	02/20/2012	02/20/2012	0100/00/00	0100/60/00	02/29/2012	
ed i iov: vT i	Anthe Samuled in Phase	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	272
126-9					:								:			; ,	5	
nash Tash Cra	Crasnes Reported In Frase	25 111 103	C 000 113	51 104 17	11 076 47	12 120 464 71	25 102 153	8 25 200 74	37 216 163	C 700 00	5/ 570.005.00	55 700 00	CI 076 47	C 020 F13	7	51 605 00	81 603 073 53	293 330 34
UV LO LO	Average Cost per month	594,411./0 697.600.45	20.000,416	321,194.12 647 060 46	\$14,0/0.4/ ent 260.00	5129,404.71	332,102.33	47.002,C26	CO./17,426	\$5,/00.00	00.000,0/ C	53,/UU.UU	544,5/0.4/	\$14,938.62 \$10,547.50	1/.401,06	01.021.02	\$52,020,020 520,020,020	+C.755,155
,	standard Deviation of Cost per Month	\$80,000.45	820,883.39	C4/202/240	\$24,508.99	\$181,/02.00	\$40,122.90	\$44,040.28	80.6/0,000	\$18,482.07	08.2/C,88&	\$18,482.07	00.726,408	\$29,047.00	79.800,026	\$5,409.10	\$02,000.8/	901,415,94
,	Difference of Averages	-\$287,366.28	\$15,352.63	\$16,865.00	-\$9,957.32	-\$19,884.00	\$17,427.44	\$34,923.26	\$7,310.71	-\$29,178.21	\$40,683.69	\$20,957.14	\$24,472.73	\$8,361.90	\$11,073.68	\$23,434.85	\$138.18	\$10,765.89
86 12 01 -7 1 40	-statistic	-4.25	2.55	1.92	-0.28	-0.61	1.00	3.04	0.27	-1.17	1.41	1.41	2.29	2.36	2.13	-1.65	0.00	-2.10
ueu sáp sei -əsi	2 Degrees of Freedom	1.14	39.72	40.10	3.45	31.54	15.32	42.00	42.00	5.38	28.34	41.71	37.56	41.00	37.00	11.81	21.80	295.82
CI VUU VUU FI	P-value	0.078	0.007	0.032	0.392	0.277	0.167	0.002	0.383	0.142	0.086	0.085	0.013	0.011	0.022	0.068	0.500	0.018
,	Significant Change (95% CI)	None	Decrease	None	None	None	None	Decrease	None	None	None	None	Decrease	Decrease	Decrease	None	None	Increase
J	Difference of Averages	\$312,738.24	-\$13,658.82	-\$12,094.12	\$25,273.53	-\$29,404.71	-\$1,196.64	-\$25,288.24	\$39,363.31	\$33,650.00	\$2,948.66	\$3,400.00	-\$36,043.14	-\$14,958.82	-\$5,164.71	\$26,144.12	\$22,813.97	\$20,532.66
98 0 5 2-3 0 7	-statistic	4.56	-1.51	-1.10	0.73	-0.56	-0.07	-2.37	1.83	1.35	0.10	0.55	-2.09	-2.08	-1.03	1.87	0.49	3.98
uen Isáj Ise-	Degrees of Freedom	1.22	16.57	19.01	3.18	27.90	14.43	16.00	35.08	5.34	24.78	7.62	21.63	16.00	16.00	11.08	8.65	276.90
CF BUY BP	P-value	0.078	0.076	0.143	0.267	0.277	0.461	0.014	0.040	0.125	0.461	0.315	0.024	0.025	0.166	0.042	0.315	0.000
r [Significant Change (95% CI)	None	None	None	None	None	None	Increase	None	None	None	None	Increase	Increase	None	None	None	Decrease
-1 J	Difference of Averages	\$25,371.96	\$1,693.81	\$4,770.88	\$15,316.21	-\$49,288.71	\$16,230.80	\$9,635.02	\$46,674.02	\$4,471.79	\$43,632.35	\$24,357.14	-\$11,570.41	-\$6,596.92	\$5,908.98	\$2,709.27	\$22,952.15	\$9,766.77
) 1- 9 21 9 21	-statistic	0.93	0.16	0.36	1.40	-1.05	1.04	0.61	1.85	0.69	1.50	1.63	-0.65	-0.82	0.82	0.97	0.51	2.23
ieq Ale seq seq	v Degrees of Freedom	38.25	30.45	35.42	55.99	20.65	43.92	49.33	35.93	46.88	40.34	48.34	24.77	24.17	45.92	37.93	44.16	737.48
O UV UV A VU	P-value	0.187	0.421	0.346	0.083	0.164	0.162	0.276	0.033	0.244	0.071	0.059	0.245	0.216	0.214	0.162	0.310	0.014
	Significant Change (95% CI)	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	Decrease

Appendix D

SUMMARY OF SIGNIFICANT CHANGE

		Analysis of Change With Aggregated Data from All Intersections	None	None	None	Increase	Decrease	Decrease	Increase	Decrease	Decrease	
99	N346	८८ स ड २१ म सड	None	None	Increase	NCR	NCR	NCR	None	None	None	
59	N241	SR 4 & Robscott Manor	None	None	None	NCR	NCR	NCR	None	None	None	
55	N663T	bA əlqqA & bA əbiəlliH	Decrease	None	None	NCR	NCR	NCR	Decrease	None	None	
2	N448T	əvfi lətzmfı 25 əvfi sgəlioD 8	Decrease	Increase	None	None	None	None	Decrease	Increase	None	
32	N438T	S College Ave & F Park Pl	Decrease	None	None	None	NCR	None	Decrease	Increase	None	
67	N467T	PC College Ave & Marvin Dr	None	None	None	NCR	NCR	NCR	None	None	None	
87	N436	4 A2 & 97A spalloD 2	None	None	None	None	NCR	None	None	None	None	
C 7	N411T	n.I avoiT & bH aotilI	None	None	None	None	NCR	None	None	None	None	
77	N414T	bH slqqA & bH notslH	None	Decrease	Decrease	NCR	NCR	NCR	None	None	None	
19	N439T	DA nobno.1 wo ^N & ovA baniovoD	Decrease	Increase	None	NCR	NCR	NCR	Decrease	Increase	None	
11	N431T	Cleveland V & South and Clanel St	None									
4	N424T	Delaware Ave & Library Ave	None	None	None	None	None	NCR	None	None	None	
=	N430T	Delaware Ave & S Chapel St	None									
9	N428T	оча одебо С & оча отвива	None	None	None	None	NCR	None	None	None	None	
4	N714T	E Main St & Pomeroy Lane	None	None	None	Decrease	NCR	Decrease	Decrease	None	None	
-	N423T	E Main St & Library Ave	None									
Intersection Number	Signal Permit No.	Significant Change (95% CI)	Phase-1 to Phase-2	Phase-2 to Phase-3	Phase-1 to Phase-3	Phase-1 to Phase-2	Phase-2 to Phase-3	Phase-1 to Phase-3	Phase-1 to Phase-2	Phase-2 to Phase-3	Phase-1 to Phase-3	۔ : : : : : : : : : : : : : : : : : : :
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