7-2011

The Effects of Pedestrian Countdown Timers on Safety and Efficiency of Operations at Signalized Intersections

Jacob N. Schmitz
University of Nebraska-Lincoln, jacob.schmitz@yahoo.com

THE EFFECTS OF PEDESTRIAN COUNTDOWN TIMERS ON SAFETY AND EFFICIENCY OF OPERATIONS AT SIGNALIZED INTERSECTIONS

by

Jacob N. Schmitz

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Civil Engineering

Under the Supervision of Professor Anuj Sharma

Lincoln, Nebraska

July 2011

THE EFFECTS OF PEDESTRIAN COUNTDOWN TIMERS ON SAFETY AND EFFICIENCY OF OPERATIONS AT SIGNALIZED INTERSECTIONS

Jacob N. Schmitz, M.S.

University of Nebraska, 2011

Advisor: Anuj Sharma

Pedestrian countdown timers are becoming common at urban and suburban intersections. The added information that pedestrian countdown timers provide to pedestrians can also be used by approaching drivers. A before and after case study on the effects that pedestrian countdown timers have on safety and efficiency of operations was performed at two signalized intersections in Lincoln, Nebraska. The effects on both drivers and pedestrians were analyzed. Performance measures for pedestrian analysis include pedestrian compliance and average pedestrian walking speed. Performance measures for the driver analysis include probability of stopping and speed at the stop bar of vehicles during the yellow phase (vehicles passing through the intersection during the yellow phase). Data was collected using a Wide Area Detector and a Pan-Tilt-Zoom video camera. Data was collected using state of the art data collection software, Wonderware, which displayed all traffic and pedestrian signal information, vehicle detections, individual vehicle speeds and distances from stop bar, and the video from the PTZ camera all on one computer screen.

Statistical models were estimated to understand the effects that pedestrian countdown timers have on the performance measures. The resulting models identified statistically significant factors that affected the performance measures. Pedestrian countdown timers

were found to increase pedestrian walking speed by 0.2 ft/sec, and decrease speed at the stop bar of vehicles during the yellow phase by 1.0 mi/hr. The probability of stopping curve became steeper after installation of pedestrian countdown timers, but the difference in probability of stopping was not statistically significant.

ACKNOWLEDGMENTS

I would like to express the most sincere thanks to my advisor, Dr. Anuj Sharma, for all of his help throughout my graduate program at Nebraska. I would like to thank him for his kindness, support, guidance, and character towards me. It has truly been an honor working for him, and I hope that our paths may cross again in the future.

Second, I would like to thank all of the graduate students at UNL who helped me throughout this project. I would especially like to thank Nate Burnett, Shefang Wang, Kevin Hock, Miao Wang, and Mo Zhao for their acts of selflessness in helping me achieve my goals. Without them, I would not have been able to finish this thesis.

I am also grateful for the members of my examining committee, Dr. Larry Rilett and Dr. Aemal Khattak. Their insight and previous project experience is greatly appreciated and has helped me tremendously in gaining practical knowledge out of this project.

I am very thankful for my wonderful wife, Lindsey. She has been so great to me, and I look forward to spending the rest of my life with her. I would also like to thank my family and friends for their support.

Above all, I would like to thank the Lord God for all of his blessings to me.

Table of Contents

Page

List of Tables iii

List of Figures v

Chapter 1 – Introduction 1

Research Objectives and Hypotheses 4

Innovations....................5

Expected Benefits 5

Report Outline....................6

Chapter 2 – Literature Review....................7

Phase Countdown Timers 7

Pedestrian Countdown Timers....................9

Summary....................13

Chapter 3 – Data Collection....................15

Intersection Selection....................15

Hardware in the Field....................17

MOXA Ethernet Network Adapter....................21

Wonderware....................22

Vehicle Data....................25

Error Assessment 26

Pedestrian Data Error Reduction 27

Driver Data Error Reduction....................28

Wide Area Detector Validation 28

Chapter 4 – Data Analysis 31
Data Collection and Number of Observations 31
Pedestrian Data Analysis Results...32
Pedestrian Compliance...32
Pedestrian Walking Speed 37
Driver Data Analysis Results...40
Probability of Stopping 40
Speed at the Stop Bar of Vehicles during Yellow Phase 48
Summary of Findings...54
Chapter 5 – Conclusions 57
List of References 59
Appendix A – Variables Used in Statistical Models 62
Appendix B – Locations of Sensys Sensors 69

List of Tables

Page

Table 1: Performance Measures Studied and Hypotheses Tested 4

Table 2: Intersection Width 16

Table 3: Crosswalk Dimensions at 17th & G 16

Table 4: Wonderware Intouch Tags at 17th St & G St 23

Table 5: Example Wonderware Historian Data 25

Table 6: Data Collection and Number of Observations Used Before Installation of PCT 32

Table 7: Data Collection and Number of Observations Used After Installation of PCT 32

Table 8: Pedestrian Compliance Model Results 36

Table 9: Pedestrian Walking Speed 37

Table 10: Pedestrian Walking Speed Model...39

Table 11: Probit Model Before Installation of PCT at S 17th St and G St 42

Table 12: Probit Model After Installation of PCT at S 17th St and G St 43

Table 13: Dilemma Zone Boundaries at S 17th St and G St 44

Table 14: Probit Model of Combined Data at S 17th St and G St 45

Table 15: Probit Model Before Installation of PCT at 27th St and Cornhusker Highway 46

Table 16: Probit Model After Installation of PCT at 27th St and Cornhusker Highway 46

Table 17: Dilemma Zone Boundaries at 27th St and Cornhusker Highway...........47

Table 18: Probit Model of Combined Data at 27th St and Cornhusker Highway 48

Table 19: Speed at Stop Bar of Vehicles during Yellow Phase Model at S 17th St and G St 51

Table 20: Speed at Stop Bar of Vehicles during Yellow Phase Model at 27th St and Cornhusker Highway 53

Table 21: Effects of Pedestrian Countdown Timers on Safety and Efficiency of Operations 55

Table 22: Hypothesis Verification 56

List of Figures

Page

Figure 1: Plot of Pedestrian Compliance from Previous Studies............................2

Figure 2: Traditional Pedestrian Signal (left) and Pedestrian Countdown Signal (right)..3

Figure 3: 17th & G Crosswalk Dimensions..17

Figure 4: Wavetronix SmartSensor Advance (http://www.wavetronix.com/products/smartsensor/200).....................18

Figure 5: Hardware in the Field..19

Figure 6: Northbound Approach at 17th & G...20

Figure 7: PTZ Camera at 17th & G...20

Figure 8: Eastbound Approach at 27th & Cornhusker..21

Figure 9: PTZ Camera at 27th & Cornhusker...21

Figure 10: Example Screenshot of Wonderware for 17th & G 24

Figure 11: Wonderware and MATLAB Screenshot...25

Figure 12: Axis Video Camera 24 Hour Response Time 26

Figure 13: MOXA Device 24 Hour Repsonse Time 27

Figure 14: Pedestrian Walking Speed Data Reduction...28

Figure 15: Example Speed vs. Distance Plot for a Single GPS Run 29

Figure 16: Overall Relative Frequency of Error for all GPS Runs at 17th & G St...30

Figure 17: Pedestrian Compliance Results 33

Figure 18: Probability of Stopping at S 17th St and G St.....................................43

Figure 19: Probability of Stopping at 27th St and Cornhusker Highway 47

Figure 20: Relative Frequency of Speed at Stop Bar of Vehicles during the Yellow Phase at 17th & G 49

Figure 21: Cumulative Distribution Function of Speed at Stop Bar of Vehicles during the Yellow Phase at 17th & G.....................................50

Figure 22: Relative Frequency of Speed at Stop Bar of Vehicles during the Yellow Phase at 27th St & Cornhusker Highway 52

Figure 23: Cumulative Distribution Function of Speed at Stop Bar of Vehicles during the Yellow Phase at 27th St & Cornhusker Highway 52

Chapter 1 – Introduction

Pedestrian countdown timers are replacing traditional pedestrian signals at many signalized intersections due to the increased information they provide to both pedestrians and drivers. The effects of pedestrian countdown timers on drivers and pedestrians need to be determined in order to justify whether their benefits outweigh their costs. The effects of pedestrian countdown timers on pedestrians have been inconsistent among studies, with some studies claiming that timers increase pedestrian compliance (1, 4, 14), whereas others report increased pedestrian erratic behavior in the presence of countdown timers (7) and a decrease in pedestrian compliance (2, 7). In addition, drivers behave differently when pedestrian countdown timers are installed compared to when pedestrian countdown timers are not installed (8). To visualize the inconsistencies among pedestrian compliance studies, Figure 1 shows a plot of the percent change in pedestrian violations after installation of pedestrian countdown timers, which includes findings from multiple studies. Each data point in Figure 1 represents an intersection where pedestrian countdown timers were installed.

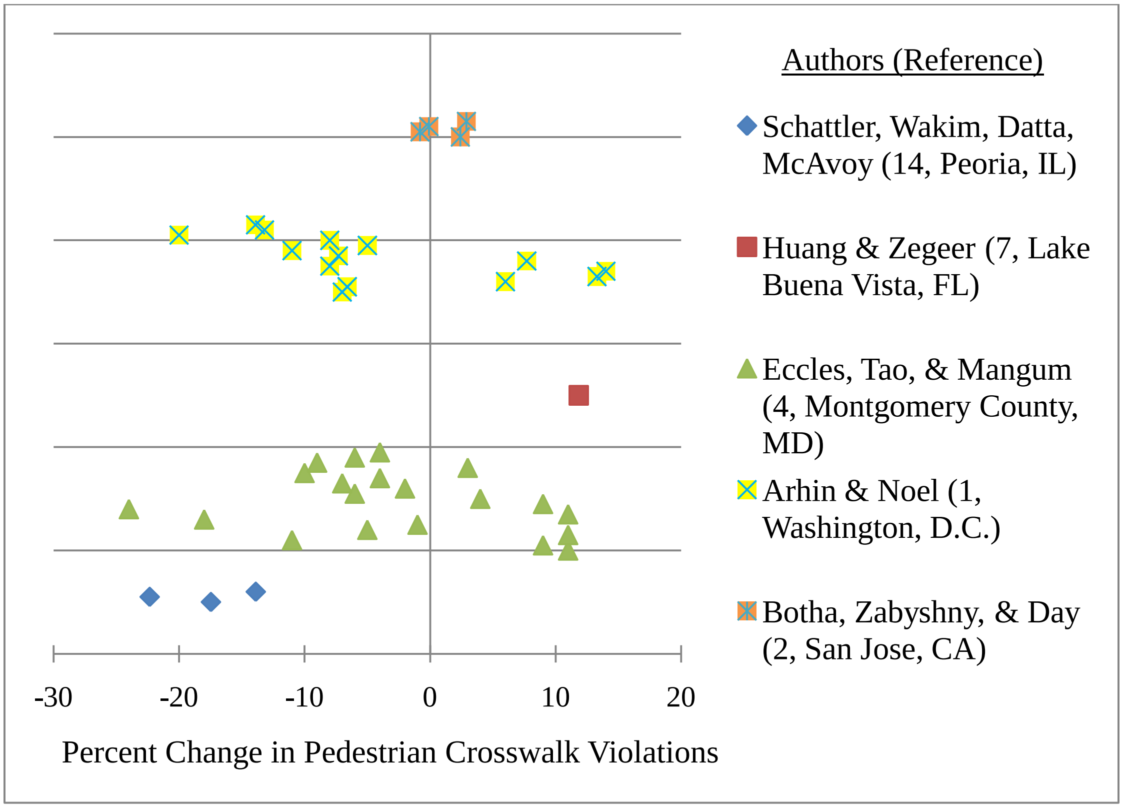


Figure 1: Plot of Pedestrian Compliance from Previous Studies

As seen in Figure 1, pedestrian countdown timers have been found to either increase pedestrian violations or decrease pedestrian violations. One possible reason of contradictory results could be variability in pedestrian behavior due to regional differences. This in turn makes it necessary to investigate the effect of pedestrian countdown timers in Nebraska. In addition, contradictory results were also found at different intersections within the same city, which could be due to site-specific intersection characteristics. Another possible reason for unexpected results is that differences in pedestrian violations may be due to other factors than pedestrian countdown timers, such as conflicting traffic, time of day, the presence of other pedestrians, etc. Using statistical modeling tools, the effects of pedestrian countdown timers can be uniquely identified, and tested for significance. This thesis presents an in-depth before and after analysis of driver and pedestrian behavior in the presence and absence of pedestrian countdown timers using statistical modeling tools.

A traditional pedestrian signal has a WALK phase, represented by either a figure of a person walking or the word "WALK", a flashing DON'T WALK phase represented by a flashing hand or by the flashing words "DON'T WALK", and a steady DON'T WALK phase represented by a solid hand or the words "DON'T WALK" displayed constantly. A pedestrian countdown signal has the same three phases as a traditional pedestrian signal; however the flashing DON'T WALK phase is represented by a flashing hand and a countdown timer that tells the amount of time left until the flashing DON'T WALK phase is over. Figure 2 shows a picture of a traditional pedestrian signal and a pedestrian countdown signal.

Figure 2: Traditional Pedestrian Signal (left) and Pedestrian Countdown Signal (right)

In all pedestrian signal types, the WALK phase is displayed when pedestrians are permitted to walk in the crosswalk. The flashing DON'T WALK phase is displayed after the walk phase and its purpose is to allow a sufficient amount of time for people who entered the crosswalk during the walk phase to cross the intersection safely. The steady

DON'T WALK phase is displayed after the flashing DON'T WALK phase. It denotes the time when it is illegal for pedestrians to be in the crosswalk because conflicting traffic has a green signal.

Research Objectives and Hypotheses

The objective of this research is to evaluate the effects that pedestrian countdown timers have on safety and efficiency of operations at two intersections in Nebraska. Statistical modeling tools were used to determine the effects that pedestrian countdown timers have on safety and efficiency. Table 1 lists the performance measures studied, the dependent variable used in each model, the coding of each dependent variable, and the hypotheses to be tested.

Table 1: Performance Measures Studied and Hypotheses Tested

Performance Measure Modeled	Dependent Variable	Dependent Variable Coding	Hypothesis (After Installation of PCT)
Pedestrian compliance	Pedestrian violation	0 (no violation) / 1 (violation)	Pedestrian compliance will increase
Pedestrian walking speed	Average walking speed of pedestrian, ft/sec	Decimal value of walking speed	Pedestrian walking speed will increase
Probability of Stopping	Vehicle goes or stops	0 (Go) / 1 (Stop)	Probability of stopping curve will become steeper
Speed at stop bar during yellow phase	Speed at the stop bar, mi/hr	Integer value of speed at stop bar	Speed at the stop bar will increase

Innovations

As will be seen in the literature review presented in Chapter 2, a limitation to previous research is that microscopic characteristics of both vehicles and pedestrians have not been analyzed in previous studies. This research is innovative because an in-depth quantitative analysis of microscopic characteristics was performed for both drivers and pedestrians before and after installation of pedestrian countdown timers. The data collected for both pedestrians and drivers will help understand the microscopic interactions among drivers and pedestrians, which lead to the macroscopic results observed. The statistical modeling results provide a better understanding of driver and pedestrian decision-making at intersections with pedestrian countdown timers than has been achieved in previous research studies.

Expected Benefits

The expected benefits of this study are a better understanding of the impacts of pedestrian countdown timers on drivers and pedestrians. With two before and after studies at separate approaches having different characteristics such as speed limit and traffic volumes, an indication of the effects of pedestrian countdown timers on both drivers and pedestrians in Lincoln, Nebraska can be seen. The statistical models will be useful in better understanding the underlying behavior of drivers and pedestrians, as well as lead to improvement in microscopic modeling tools.

Report Outline

Chapter 2 is composed of a thorough literature review of the effects of pedestrian countdown timers on safety and efficiency of operations at signalized intersections. Chapter 2 is divided into two sections: phase countdown timers (used outside of the U.S.) and pedestrian countdown timers.

Chapter 3 describes the sites used for data collection. The hardware deployed for data collection is explained. Then, the error reduction techniques are described. Chapter 3 concludes with the error tolerance of the hardware components in the field.

Chapter 4 explains the data analysis of this study. The days of data collection and the number of observations used in data analysis are presented, followed by the results of this study. This thesis ends with Chapter 5, which contains the conclusions drawn from this research.

Chapter 2 – Literature Review

There have not been many studies evaluating the effects of pedestrian countdown timers on traffic operations characteristics such as dilemma zone boundaries, and velocity of vehicles during the yellow phase. Almost all literature on pedestrian countdown timers has focused on pedestrian safety, pedestrian compliance, pedestrian understanding, red light runners, and pedestrian-vehicular conflicts. However, some research has been performed on phase countdown timers, primarily used in Asia, to quantify effects of phase countdown timers on traffic characteristics. Therefore, the literature review will cover research done on pedestrian countdown timers and phase countdown timers in order to gain a thorough understanding of the effects that both pedestrian countdown timers and phase countdown timers have on efficiency of operations and safety at signalized intersections.

Phase Countdown Timers

Signalized intersections are important nodal points in transportation networks and their efficiency of operation greatly influences the performance of the entire network. Several European and Asian countries have started using phase countdown timers to provide additional information to drivers, such as time until the beginning of the green phase. In the U.S. there is still a debate going on regarding whether to provide phase countdown timers, but several pedestrian countdown timers have been installed to provide additional information to pedestrians. The presence of these timers is expected to affect both driver and pedestrian behavior. Drivers may react differently on the onset of yellow because they will have additional information on the time until the onset of yellow. This can affect both safety and efficiency of performance of both vehicles and pedestrians at signalized intersections.

He et al. (6) performed a study of drivers' perceptions of phase countdown timers in Beijing, China. They surveyed 200 drivers and were interested in the driver's perception of the effects that phase countdown timers have on driving behaviors and intersection safety. They found that 75% of the surveyed drivers thought that phase countdown timers could help them avoid using the emergency brake at the onset of the amber phase. There was an overall consensus of all drivers that phase countdown timers can:

- Reduce driver waiting anxiety by informing them of the time until the next phase
- Provide a reference for drivers on when to turn off and turn on their engines in order to save fuel and help the environment
- Provide more information than traditional traffic signals.

Furthermore, they found that 87.5% of surveyed drivers prefer phase countdown timers to traditional traffic signals. In addition, they found that 86.0% of drivers believed that intersections with phase countdown timers are safer than traditional traffic signal intersections. Other studies have been performed to analyze the effects that phase countdown timers have on drivers (10, 17), which mainly focus on queue discharge characteristics.

Pedestrian Countdown Timers

Schattler et al. (14) performed a study in Peoria, IL using a total of 13 intersections to study the effect of pedestrian countdown timers on pedestrian compliance, yellow light runners, and red light runners. In the study, three intersections were studied using a before-and-after method, and ten intersections were studied using a comparative analysis method (five intersections with pedestrian countdown timers installed and five with traditional pedestrian signals). They found that pedestrian countdown timers do not significantly increase or reduce the amount of red-light runners and yellow-light runners.

A comparative analysis at ten intersections also resulted in no significant differences in YLR and RLR between the intersections with pedestrian countdown timers installed and the intersections with traditional pedestrian signals. They also found that pedestrian countdown timers significantly improve pedestrian compliance over traditional pedestrian signals. The proportion of pedestrians that started walking during the walk or flashing DON'T WALK (with countdown numbers) was higher after installation of pedestrian countdown timers than with traditional pedestrian signals. At each intersection studied, the percentage of pedestrians crossing during the "WALK" phase (W) and flashing "DON'T WALK" phase (FDW) increased after installation of pedestrian countdown timers. They performed a Z-test at 95% confidence and found that the average pedestrian violation rate over the three intersections (% Peds. Crossing on DW) significantly decreased after installation of pedestrian countdown timers.

Huang and Zegeer (7) performed a treatment and control study on five intersections, two treatment intersections had pedestrian countdown timers installed, and three control intersections had traditional pedestrian signals. Three measures of effectiveness were studied: 1. Pedestrian compliance with the Walk Signal, 2. Pedestrians who ran out of time, and 3. Pedestrians who started running when the flashing DON'T WALK signal appeared. A pedestrian who complied with the walk phase began walking in the crosswalk during the Walk phase, and did not comply by beginning to walk in the crosswalk during any other phase. They found that pedestrian compliance to the walk signal was significantly lower at intersections with pedestrian countdown timers, using the chi-squared method at the 0.005 significance level. A pedestrian who ran out of time was still walking in the crosswalk at the beginning of the DON'T WALK phase. They found an insignificant difference in the proportion of pedestrians who ran out of time. They found that pedestrian countdown timers reduce the amount of pedestrians who start running when the flashing DON'T WALK appears. This is because pedestrians are aware of how much time they have to cross the intersection before the solid DON'T WALK signal appears, and can adjust their speed accordingly, not needing to run as often. They concluded that pedestrian countdown signals are not recommended for use in the state of Florida because of the negative effect of decreasing pedestrian compliance to the Walk signal.

Huey and Ragland (8) found that drivers behave differently based on what type of pedestrian signal is used. They tested two intersections for red-light runners and yellow-light runners using traditional pedestrian signals and pedestrian countdown signals. They found that with a pedestrian countdown timer installed, 67.5% of the vehicles observed at the onset of yellow went through the intersection (observed from roughly 80 ft upstream of the intersection). With a traditional pedestrian signal, 65.3% of the vehicles went through the intersection. The difference was not found to be statistically significant.

Ma et al. (11) studied the effects of pedestrian countdown timers on pedestrians in Shanghai, China. A comparative analysis was performed at two intersections, one with pedestrian countdown timers installed and one with traditional pedestrian signals. They studied pedestrian compliance in terms of pedestrians who enter the intersection during the flashing DON'T WALK phase. Two age groups were considered: younger and elder. Pedestrian countdown timers were found to increase pedestrian compliance in elder people. For younger people, the proportion of pedestrians who enter the crosswalk during the flashing DON'T WALK phase is about the same for both pedestrian countdown signals and traditional pedestrian signals.

Washburn et al. (19) performed a before and after study in Gainesville, FL at five intersections to study the effects of pedestrian countdown timers on pedestrians. They mainly studied pedestrian compliance, by calculating the percentage of pedestrians entering the crosswalk during the WALK, FDW, and DW indications. In addition, they took a further look into the compliance with the FDW indications. Percentage of pedestrians hesitating, running, or going back to the starting curb was calculated, as well as percentage of pedestrian-vehicle conflicts. Washburn et al. found that the proportion of pedestrians entering on the WALK indication increased at three of the five intersections. Correspondingly, the proportion of pedestrians entering on the DW interval decreased at the same three of the five intersections. It was found that there was no increase in the proportion of pedestrians who entered during the FDW interval. In addition, the pedestrian countdown timers had the positive effect of increasing the proportion of pedestrians exiting on the FDW interval as opposed to the DW interval. There was no trend in erratic pedestrian behavior, such as hesitating, running, or going back to the starting curb. There was no significant increase or decrease in pedestrian-vehicle conflicts. Overall, Washburn et al. found no negative effects of pedestrian countdown timers and found positive effects including pedestrian compliance.

Eccles et al. (4) performed a before and after pedestrian countdown timer study of five intersections in Montgomery County, Maryland. Eccles et al. studied pedestrian compliance by counting the amount of pedestrians who entered the crosswalk during each phase: WALK, flashing DON'T WALK, and solid DON'T WALK. Vehicle approach speeds were measured by radar from approximately 400 ft upstream of the intersection. Only vehicles that were unobstructed by other vehicles and that were recorded between 17 to 6 seconds from the onset of red were used for analysis. There was a significant decrease in mean speed at one approach; otherwise, there were no significant changes in mean speeds after installation of pedestrian countdown timers.

For the pedestrian compliance study, Eccles et al. studied each crosswalk separately at the five intersections, for a total of 20 crosswalks. It was found that six out of 20 crosswalks had a significant increase in pedestrian compliance, which was measured as percentage of pedestrians entering the crosswalk during the WALK indication, at the 95% confidence level. It was also found that two of the 20 crosswalks had a significant decrease in pedestrian compliance. The other 12 crosswalks had insignificant results in pedestrian compliance.

Schrock and Bundy (15) studied the effects of pedestrian countdown timers on drivers in Lawrence, Kansas in a comparative analysis of a total of four intersections, two with pedestrian countdown timers installed and two with traditional pedestrian signals, along the same corridor. Vehicle speeds were measured using LIDAR from observers located downstream of the intersection, facing oncoming traffic. Vehicles that were located in the indecision zone during the flashing DON'T WALK phase were used for data. Vehicles were categorized into one of the following categories: stopped (began decelerating at or after the beginning of the amber phase); stopped but began decelerating early (before the beginning of the amber phase); continued on normally through the intersection; continued on through the intersection but accelerated in order to do so; and continued on through the intersection but ran the red light in order to do so. They found a significant decrease in drivers who accelerated in order to continue through the intersection when a pedestrian countdown timer is present. They concluded that drivers in the indecision zone were found to drive less aggressively at intersections with pedestrian countdown timers installed.

Summary

Other previous studies (1, 2, 9, 12, and 24) have studied the effects of pedestrian countdown timers on pedestrians and drivers with mixed results. Pedestrian countdown timers have been reported to have both positive and negative effects on drivers and pedestrians in different studies. Therefore, it is important to study the effects of pedestrian countdown timers on both drivers and pedestrians in Lincoln in order to understand the advantages and disadvantages of pedestrian countdown timers specific to Lincoln drivers and pedestrians.

Chapter 3 – Data Collection

Intersection Selection

After a thorough literature review, a detailed research plan and methodology was presented to the Nebraska Department of Roads Traffic Advisory Committee (TAC) on June 4, 2009. The TAC, consisting of professionals from the State of Nebraska Department of Roads and the City of Lincoln Public Works Department, chose two intersections to perform the study in Lincoln, Nebraska: S 17th St & G St and N 27th St & Cornhusker Highway. It was determined that the best approaches to perform the study were the northbound approach at 17th St & G St, and the eastbound approach at 27th St & Cornhusker Highway. At both of these locations, the pedestrian countdown timers can easily be seen by oncoming traffic at distances over 500 ft. Other technical constraints, met at both intersections selected, needed for this study were:

- Presence of pedestrian signal recall: This will ensure that the countdown is displayed at every cycle.
- Presence of space in the cabinet: Enough space in the traffic cabinet to accommodate the instrumentation for data collection purposes.
- Availability of exterior hardware component storage: Mast arms (no span wires) were needed to hold the wide area detectors, and light poles were needed to hold PTZ cameras, etc.

Table 2 lists the intersection width at the two intersection approaches used to perform this study.

Table 2: Intersection Width

Intersection	Approach	Intersection Width (ft)
17th & G	NB	95
27th & Cornhusker	EB	160

Due to an inability to obtain accurate pedestrian walking speeds at 27th & Cornhusker, explained in detail later, pedestrian data was only reduced at the intersection of 17th St & G St.

Exact measurements of the four crosswalks were measured at S 17th & G St. Table 3 lists the length and width of each crosswalk at the intersection of 17th & G. Figure 3 shows the intersection of 17th & G with the crosswalk dimensions shown.

Table 3: Crosswalk Dimensions at 17th & G

Leg	North	South	East	West
Length, ft	41.32	42.04	41.23	39.78
Width, ft	12.33	13.33	10.25	11.92

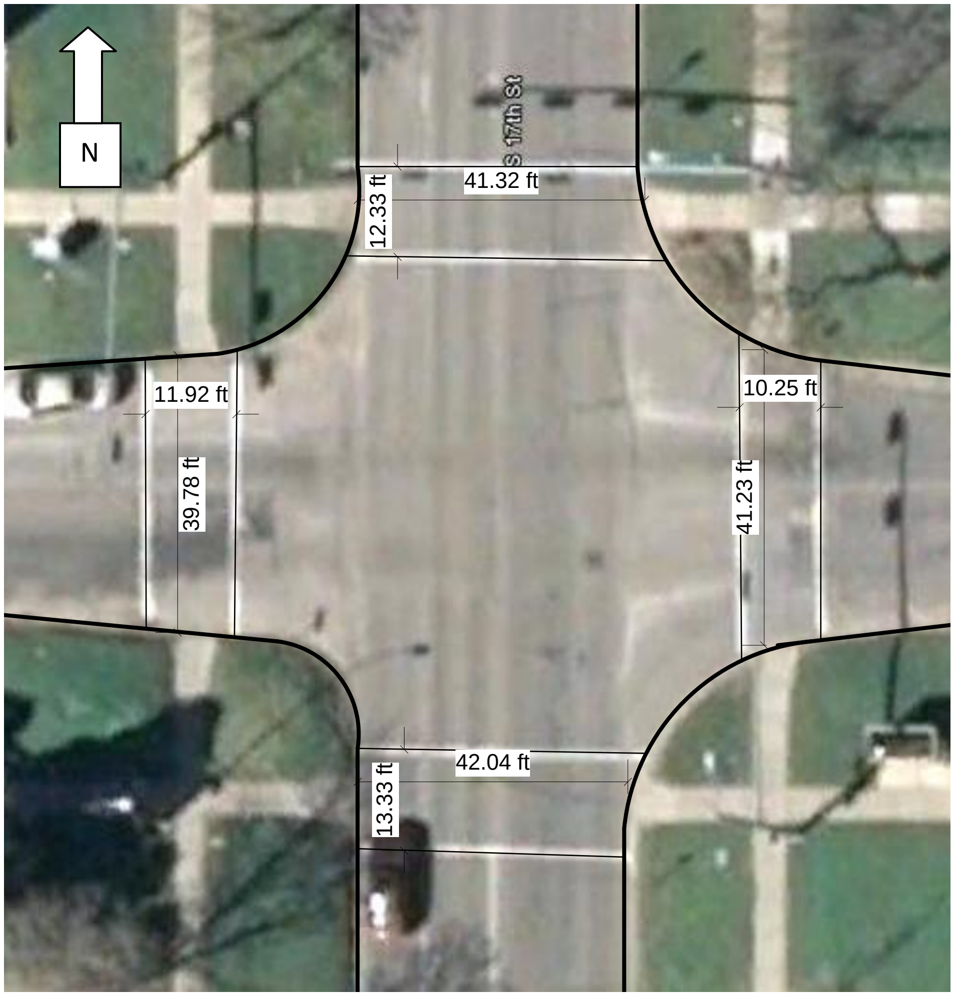


Figure 3: 17th & G Crosswalk Dimensions

Hardware in the Field

In order to satisfy the performance measures of the project, many hardware components were needed in the field. For all pedestrian performance measures, a Pan Tilt Zoom (PTZ) camera was needed. A wide area detector was needed to collect data needed for probability of stopping curves and the speed at the stop bar of vehicles during the yellow phase. MOXA I/O devices, explained later, were used to collect the traffic and pedestrian signal phase information.

For wide area detection, the Wavetronix SmartSensor Advance was used. The Wavetronix SmartSensor Advance has a detection range of 500 ft, and was installed on the traffic signal mast arm at both locations. Figure 4 shows the detection area of the Wavetronix SmartSensor Advance.

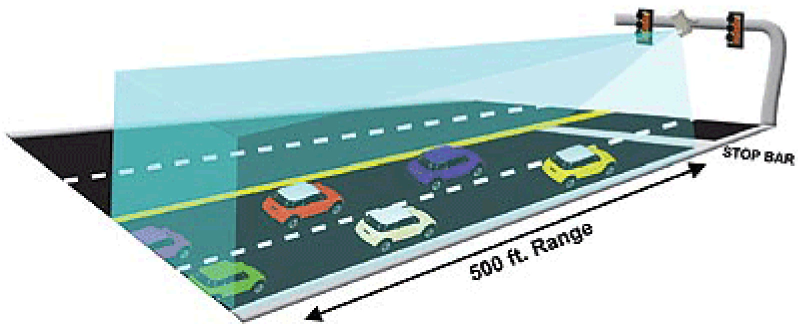


Figure 4: Wavetronix SmartSensor Advance (http://www.wavetronix.com/products/smartsensor/200)

The Wavetronix sensor has the ability to track individual vehicles, and display their locations and speeds instantaneously. In addition, all vehicular location and speed information is stored in a database for future retrieval. By pairing up the Wavetronix information and the video captured by the PTZ camera, the instantaneous speed of each vehicle in the video was displayed.

The Sensys Wireless Vehicle Detection System was used for the stop bar and advance detectors. The Sensys Wireless Detection System has four components: flush-mount wireless sensors, a repeater, an access point, and contact closure cards. Three wireless sensors were needed per lane, one stop bar detector and two advance detectors. A repeater was needed to relay the advance detector information to the access point, which transfers the data to the contact closure card located inside the traffic cabinet. The access point also relays the stop bar detectors information to the contact closure card. Figure 5 shows the relative locations of each hardware component in the field. Appendix B shows the actual dimensions between hardware components installed at both intersections.

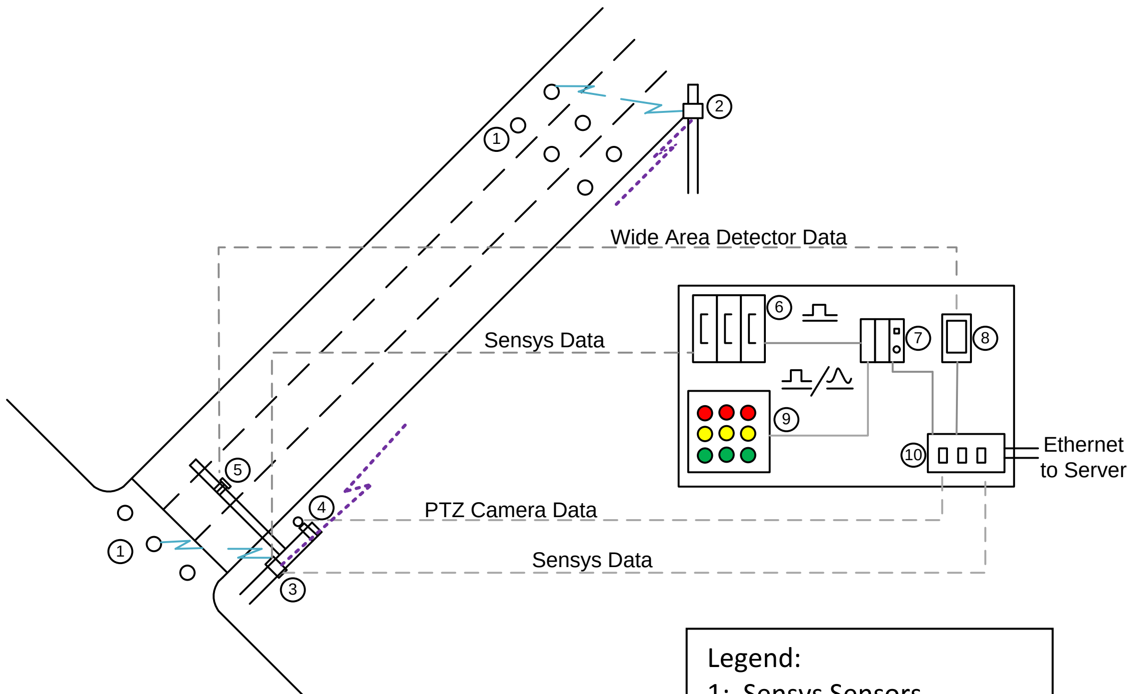


Figure 5: Hardware in the Field

Pictures of 17th & G and 27th & Cornhusker were taken after installation of the hardware in the field. Figure 6 shows a picture of the northbound approach at 17th & G. 7 shows a picture of the PTZ camera at 17th & G. It is located on the northwest corner of 17th & G.

Figure 6: Northbound Approach at 17th & G

Figure 7: PTZ Camera at 17th & G

Figure 8 shows a picture of the eastbound approach at 27th & Cornhusker. Figure 9 shows a picture of the PTZ camera installed at the 27th & Cornhusker intersection – it is the lowest camera installed on the pole.

Figure 8: Eastbound Approach at 27th & Cornhusker

Figure 9: PTZ Camera at 27th & Cornhusker

MOXA Ethernet Network Adapter

In order to use the data collected by the Wavetronix sensor, MOXA devices were needed. Two types of MOXA devices were used: an Input/Output box and an Ethernet Network

Adapter (Modbus/TCP). The I/O box has 16 digital I/O channels, which took information from the traffic signals and Sensys sensors, and connected to the Ethernet Network Adapter. The Ethernet Network Adapter connected to the City of Lincoln network. The information was accessed from the City of Lincoln Public Works Department Engineering Services office, where a server computer collected all data.

Wonderware

To view the information collected in the field in real-time, the software Wonderware was used. Wonderware has the ability to take MOXA information and display it on a computer screen with the live video from the PTZ camera. Wonderware Intouch Tags were created and assigned to each individual MOXA channel. Table 4 lists the MOXA channel, Intouch Tag, and corresponding field data used at 17th St & G St. Similarly, field data from 27th St & Cornhusker Hwy were assigned Intouch Tags from MOXA channels.

Table 4: Wonderware Intouch Tags at 17th St & G St

MOXA Channel	Intouch Tag	Field Data
0	10001	Phase 2 (17th) Red
1	10002	Phase 2 (17th) Yellow
2	10003	Phase 2 (17th) Green
3	10004	Phase 2 (17th) Pedestrian Flashing DON'T WALK
4	10005	Phase 2 (17th) Pedestrian Walk
5	10006	Phase 4 (G) Pedestrian Flashing DON'T WALK
6	10007	Phase 4 (G) Pedestrian Walk
7	10008	Sensys 300A
8	10009	Sensys 30C4
9	10010	Sensys A9A9
10	10011	Sensys 3063
11	10012	Sensys 30CD
12	10013	Sensys A9BF
13	10014	Sensys 3094
14	10015	Sensys 30F8
15	10016	Sensys AA17

An example screen shot of Wonderware, Wavetronix, and a flow chart of information is presented in Figure 10. Wonderware can show the video from the PTZ camera, display which detectors are sending pulses, display the timestamp, and display all phase information for both traffic signals and pedestrian signals. In addition, Wonderware stores all information in a historian that can be sorted and reduced. Data from a certain time and date can be extracted easily and further analyzed. The computer screen can be recorded at a 15-frames-per-second resolution.

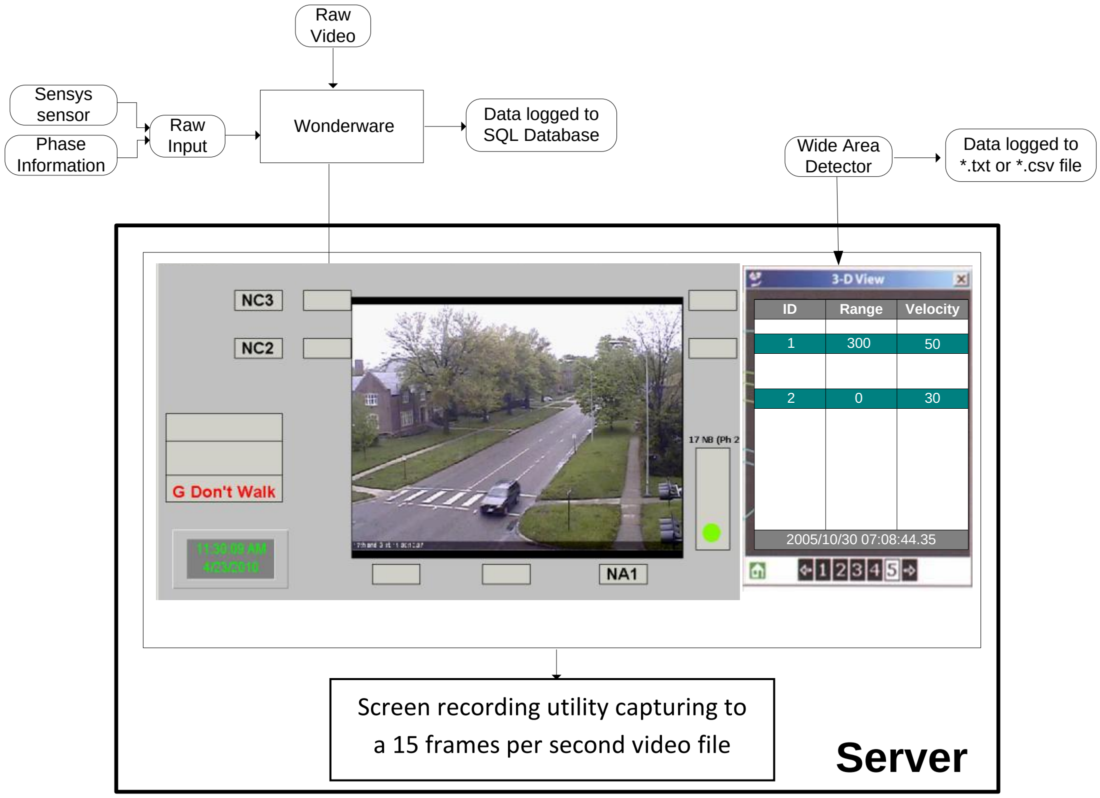


Figure 10: Example Screenshot of Wonderware for 17th & G

Information from the Wonderware Historian can be accessed from Microsoft Excel by obtaining data using a Microsoft Query, and typing in a Structured Query Language (SQL) command. An example Wonderware Historian data set is shown in Table 5. In Table 5, a value of 0 represents a time when the pedestrian phase was not flashing DON'T WALK. A value of 1 means that the pedestrian signal phase was flashing DON'T WALK. The example data presented in Table 5 shows one pedestrian signal cycle on July 9, 2010. During this cycle, the flashing DON'T WALK phase began at 12:01:46 a.m., and ended at 12:01:56 a.m.

Table 5: Example Wonderware Historian Data

TagName	Date & Time	Value
17th_FDW	2010-07-09 00:00:56.217	0
17th_FDW	2010-07-09 00:01:46.197	1
17th_FDW	2010-07-09 00:01:56.190	0

Vehicle Data

The software MATLAB was used to plot vehicle speed and distance from the stop bar instantaneously. The plot was positioned next to the Wonderware screen, so that each vehicle could be seen as it was being plotted. MATLAB stored all vehicle speed and distances from the stop bar in files that can be accessed for data reduction purposes such as dilemma zone boundaries. Figure 11 shows a screenshot of the MATLAB plots next to the Wonderware screen.

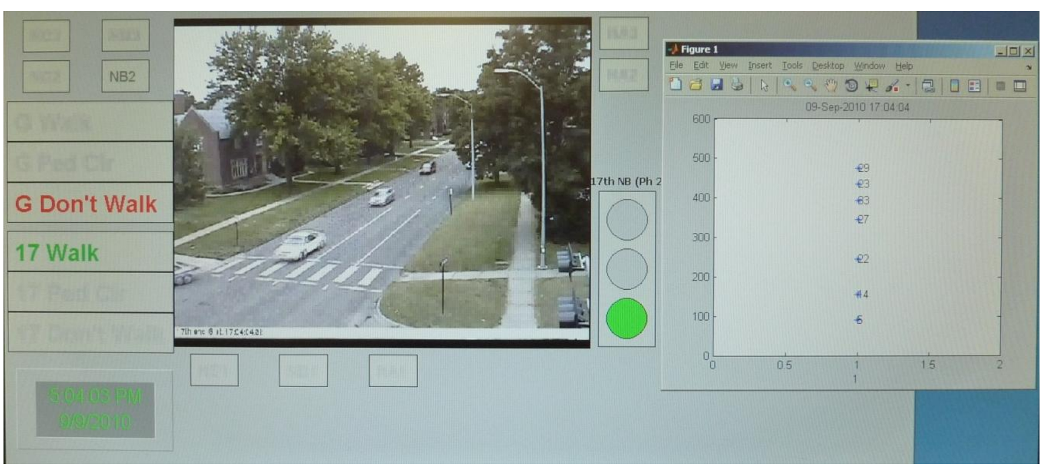


Figure 11: Wonderware and MATLAB Screenshot

Error Assessment

To assess the amount of error incurred while collecting and reducing data, many techniques were employed. First, it was important to know exactly the time difference between the video that was displayed on screen and the time the video was taken in the field. The video camera's maximum response time (delay) was 2.9 ms. Figure 12 shows a graph of the response time over a 24-hour period for the Axis video camera used at S 17th St.

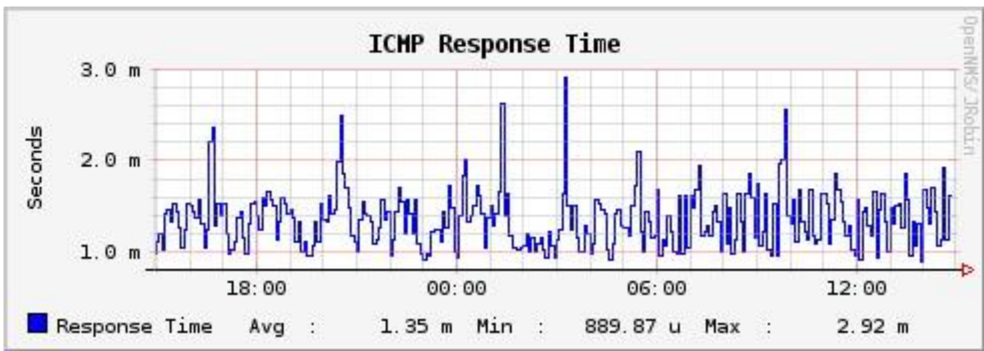


Figure 12: Axis Video Camera 24 Hour Response Time

The same procedure was done for the MOXA device at S 17th St. The MOXA device relays all signal phase, pedestrian phase, and underground sensor information. The maximum ping time was slightly higher for the MOXA device, at 11.3 ms; however, the average ping time was 1.3 ms. Figure 13 shows a graph of the response time over a 24-hour period for the MOXA device used at S 17th St.

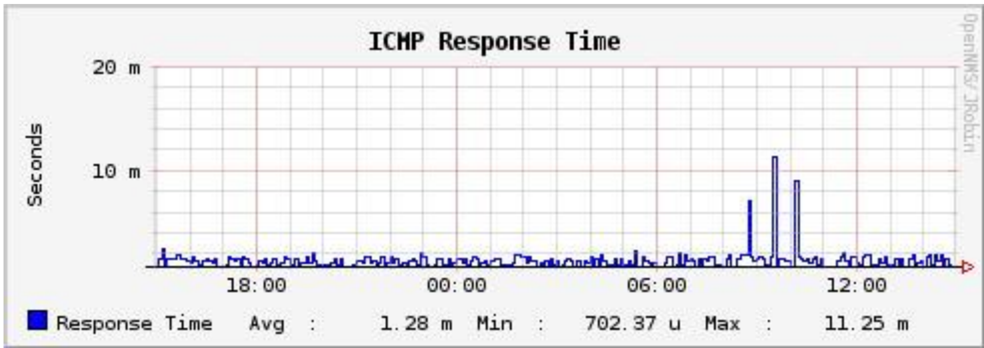


Figure 13: MOXA Device 24 Hour Repsonse Time

Pedestrian Data Error Reduction

When reducing the pedestrian data, it was necessary to be consistent in recording when a pedestrian arrived at a certain location. This was especially important when calculating pedestrian walking speeds. The video data was accurate to about 0.1 seconds, because it recorded data at 15 frames per second and displayed data to the nearest hundredth of a second. Data was recorded to the nearest 0.01 second, but walking speed results were calculated to the nearest 0.1 ft/sec to reflect the highest accuracy possible.

Pedestrian arrival times were determined by the time when a pedestrian's first foot crossed a line drawn on a transparency, which was attached to the computer screen, at ten feet increments at 17th & G. This helped determine when pedestrians reached the locations, and in turn helped calculate pedestrian walking speed with more accuracy. Between each ten-foot line, smaller dashes were drawn, indicating one foot. Figure 14 shows a picture of the transparency used for pedestrian data reduction.

Figure 14: Pedestrian Walking Speed Data Reduction

It was found that at 27th St and Cornhusker Hwy, the pedestrian arrival times could not be accurately determined. The video camera was positioned over 150 ft away from pedestrians, and at a difficult angle to see exactly when pedestrians arrived at certain locations, including the beginning and ending of the crosswalk. Calculations of pedestrian walking speed would have been inaccurate. Pedestrian violations were difficult to determine due to the uncertainty of when the pedestrian entered/exited the crosswalk. Therefore, due to inaccuracy in data collected at 27th & Cornhusker, the effects of pedestrian countdown timers were analyzed using data from 17th St & G St.

Driver Data Error Reduction

Wide Area Detector Validation

The accuracy of the Wide Area Detector (WAD) was crucial in this project. The accuracy of the WAD was tested using a vehicle equipped with a GPS unit capable of capturing data at a 100-Hz rate was used. The vehicle was driven with the GPS unit inside, capturing time, location, speed, and other data every 1/100 seconds. At the same time, the WAD was collecting data. The WAD collects individual vehicle data at rates determined by site characteristics. The WAD collects and stores vehicle ID, range (in 5 ft increments), and speed data. A graph showing speed versus distance from stop bar of the particular vehicle was created from the data captured: one line with GPS data, one line with WAD data, and one line with forecast GPS data. The forecast GPS data line was created in order to compare the two lines at specific distances. Figure 15 shows an example of a speed vs. distance graph.

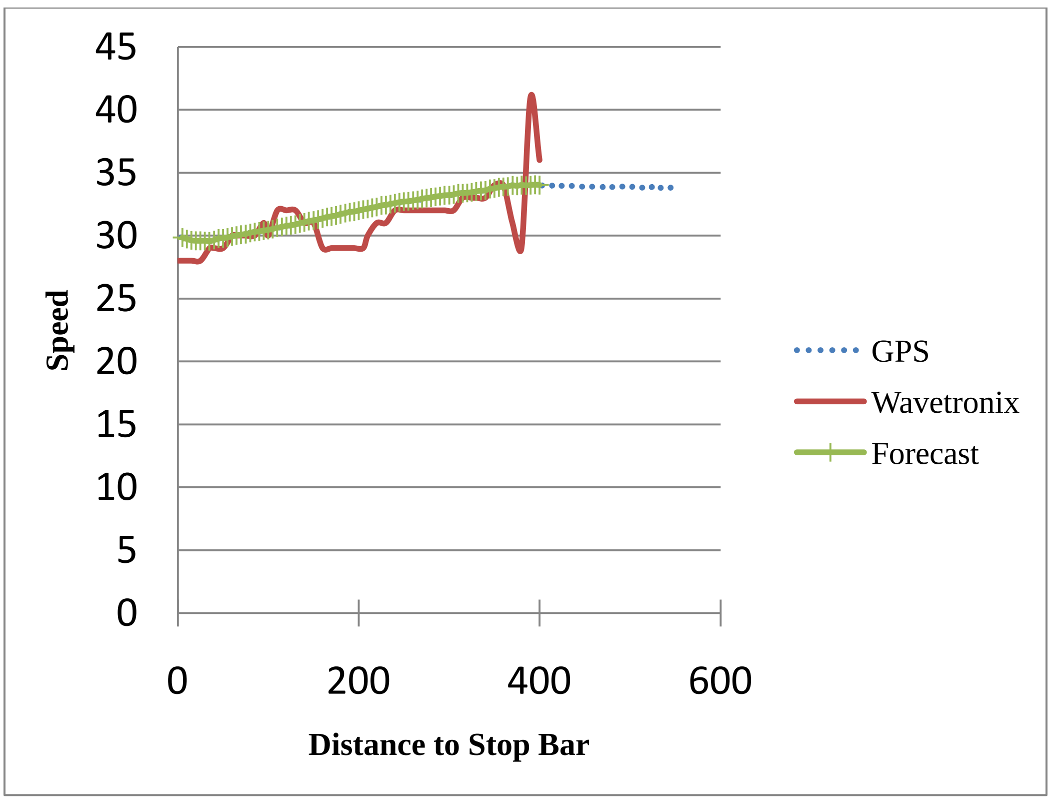


Figure 15: Example Speed vs. Distance Plot for a Single GPS Run

Data obtained from the GPS were interpolated to obtain readings corresponding to WAD observations. The error in speed (mi/hr), equal to the difference in speed between the GPS data and WAD data, was calculated for every data point collected by the WAD. A probe vehicle made nine data collection runs at each intersection. The relative frequency plot of the error in speed at 17th St & G St is shown in Figure 16.

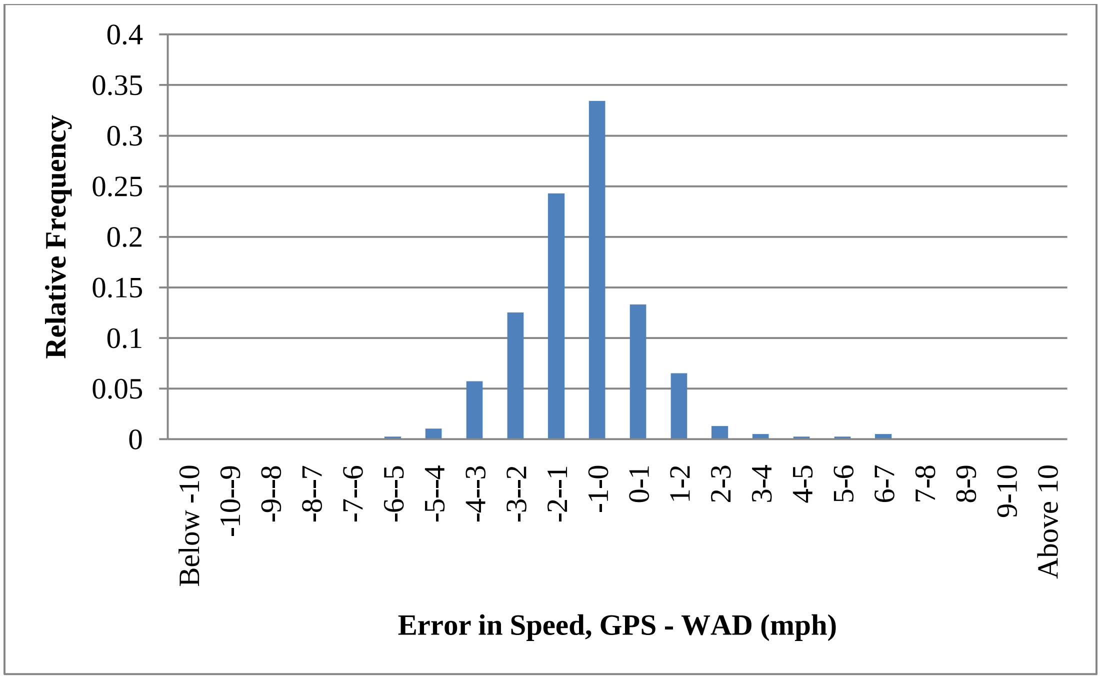


Figure 16: Overall Relative Frequency of Error for all GPS Runs at 17th & G St

As mentioned previously, the error in speed between the GPS data and the WAD data was calculated for each data point collected by the WAD. The combined data from all data collection runs was used to find the mean value of error. The mean value of error in speed for all GPS runs at 17th & G St was -0.83 mi/hr. Similar results were found at 27th & Cornhusker Highway, in that the mean value of error in speed for all GPS runs at 27th & Cornhusker Highway was -0.91 mi/hr. To further reduce potential error, only the lead vehicles were considered in instances of multiple vehicles approaching the intersection at the onset of yellow.

Chapter 4 – Data Analysis

Data Collection and Number of Observations

At 17th Street & G Street, vehicle data was collected at the northbound approach, and pedestrian data was collected at the east crosswalk (parallel to 17th St). At 27th & Cornhusker Highway, vehicle data was collected at the eastbound approach. For both intersections, data was collected from April 2010 – May 2011. A thorough data reduction process was used to eliminate possible erroneous data. All data was visually inspected before being reduced and only data during fair weather days (no precipitation) was used. In addition, no data collected during December 2010 – February 2011 was used due to extreme cold temperatures experienced, and ice/snow on roadways. The daily high temperature was used as an independent variable in the statistical models. Studies have shown that probability of stopping curves, developed from probit models, stabilize using a small sample size of approximately 150 observations (18, 25). In this study, over 400 data points were collected at each location before and after installation, which is a sufficient amount of data based on previous research findings (18, 25). Tables 6 and 7 list the number of days of data collection, and number of observations used in the data analysis of this study for both intersections, before and after installation of pedestrian countdown timers, respectively.

Table 6: Data Collection and Number of Observations Used Before Installation of PCT

Intersection	Number of Days Data Collected	Number of Pedestrian Observations	Number of Driver Observations
S 17th St & G St	49	954	429
27th St & Cornhusker Highway	14	-	525

Table 7: Data Collection and Number of Observations Used After Installation of PCT

Intersection	Number of Days Data Collected	Number of Pedestrian Observations	Number of Driver Observations
S 17th St & G St	35	500	422
27th St & Cornhusker Highway	14	-	482

Pedestrian Data Analysis Results

Pedestrian Compliance

A pedestrian is non-compliant to a pedestrian signal when he/she is inside the crosswalk during the solid DON'T WALK (DW) phase. There are two ways to achieve non-compliance: by entering the crosswalk during the solid DON'T WALK (DW) phase and by being inside the crosswalk when the phase changes from Flashing DON'T WALK (FDW) to DW. According to Jim Davidsaver of the City of Lincoln Police Department (personal communication, August 17, 2010), in the City of Lincoln, it is not a violation for a pedestrian to enter an intersection during the FDW phase as long as that pedestrian exits the intersection before the DW phase begins. Figure 17 shows the average amount of pedestrian violations per 100 pedestrians who had the potential to commit the violation listed. For this study, a pedestrian had the potential to commit a violation when he/she arrived during DW or FDW. For example, before installation of pedestrian countdown timers, an average of 80 pedestrians arrived during DW and entered the crosswalk during DW, per 100 pedestrians that arrived during DW. The average amount of pedestrian violations per 100 pedestrians who had the potential to commit the violation is considered the percentage of pedestrian violations.

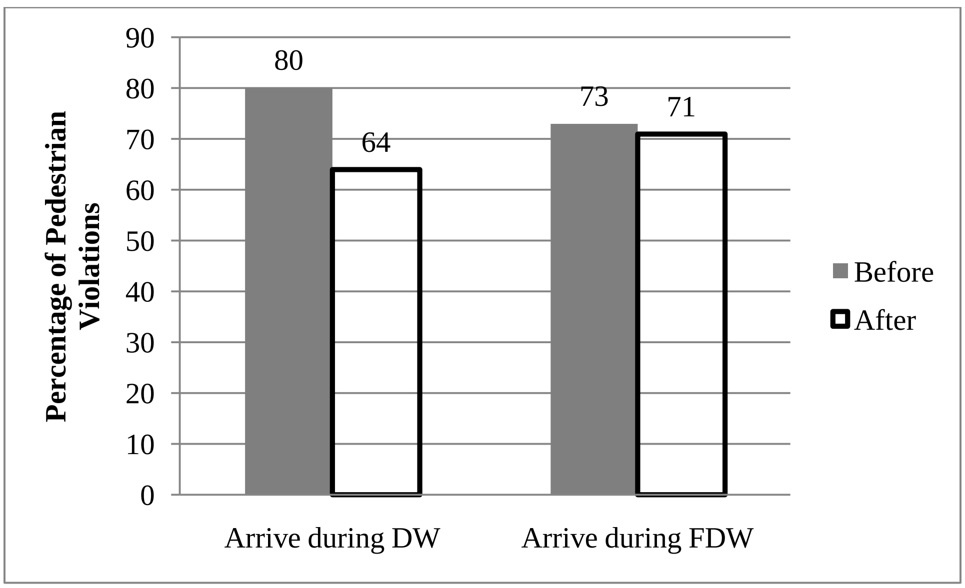


Figure 17: Pedestrian Compliance Results

It can be seen in Figure 17 that after installation of pedestrian countdown timers, the percentage of pedestrian violations decrease for both pedestrians that arrive during DW, and pedestrians that arrive during FDW. Because parameters outside the control of the investigator were present, such as conflicting traffic volume, the presence of other pedestrians in the crosswalk during the time of crossing, etc., statistical modeling tools were used to ascertain whether pedestrian countdown timers were responsible for an observed change. For an in-depth analysis of pedestrian compliance, the probability of a pedestrian violation was modeled.

Pedestrians can be either compliant or not compliant to the pedestrian signal. This can be modeled using a probit model corresponding to the probability of a pedestrian violating a pedestrian signal. The probit model is a binary choice model that takes the form:

$\Pr(Y = 1 \mid X) = \Phi(X'\beta)$, where:

Pr(Y =1 | X) is the probability that the dependent variable is equal to 1 given the independent variable X. This can be calculated using the CDF of the standard normal distribution function, $\Phi(X'\beta)$, where β is estimated parameters using maximum likelihood. In the pedestrian compliance model, the dependent variable tested was the probability of a violation. Examples of independent variables (type) used were:

- Five minute conflicting traffic volume (Integer)
- High temperature, °F (Integer)
- Day of week (Dummy)
- Time of day (Dummy)
- Average walking speed, ft/sec, of pedestrian (Decimal)
- Presence of a car stopped on G St (Dummy)
- Presence of another pedestrian inside the crosswalk (Dummy)

- Phase that the pedestrian arrived during: WALK, FDW, or DW (Dummy)
- Pedestrian delay time, sec, measured from time of arrival to time of departure (Decimal)
- Direction of travel (Dummy)
- Presence of pedestrian countdown timers (Dummy)

Appendix A provides a complete list of all variables used, type of variable, and the coding of the variable in the software used to model the results. The software NLOGIT 4.0, from Econometric Software, Inc. (22) was used to model the results. Among the statistical models tested, the Akaike Information Criterion (AIC) value was used to determine which model was the best fit (23). The AIC value was calculated as follows:

$AIC = 2 \cdot n - 2 \cdot \ln(L)$, where:

n = number of parameters in statistical model, and

L = maximum value of likelihood function for the statistical model

When comparing two statistical models, the model with the lower AIC value was chosen as the preferred model of the two. Table 8 lists the results of the pedestrian compliance model.

Table 8: Pedestrian Compliance Model Results

Probit Model		
Dependent Variable: Pedestrian Violation (0 = no violation, 1 = violation)		
Number of observations: 1454		
Unrestricted Log Likelihood = -788.389		
Restricted Log Likelihood = -1358.735		
AIC = 1.097 McFadden R^2 = 0.420		
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	-2.824	-16.207
5 min right turning traffic vol 17th St (Integer)	-0.070	-2.656
Presence of another pedestrian (Dummy)	0.092	2.832
Arrive during DW (Dummy)	3.537	23.451
Arrive during FDW (Dummy)	3.714	21.555
Delay time (Decimal)	-0.097	-6.121
Presence of pedestrian countdown timers (Dummy)	-0.012	-0.117

At 95% confidence, the following is a list of independent variables that were significant: five minute right turning volume on S 17th St, presence of another pedestrian inside of the crosswalk, arrived during DW, arrived during FDW, and delay time (s). The presence of pedestrian countdown timers was not found to be a statistically significant variable in the probability of a violation model because the absolute value of the calculated t-statistics value was less than the critical value of 1.96.

As expected, the probability of a violation decreased with an increase in conflicting traffic, and the probability of a violation increased with the presence of another pedestrian and an arrival during DW or FDW. It is surprising that the probability of a violation decreases with an increase in delay time because pedestrians would seemingly get impatient and perform risky behavior when subjected to long delay times. It is possible that the reason that delay time decreases the probability of a violation is that pedestrians who had the longest delay time waited for the WALK signal and were compliant. Frequently, pedestrians who arrived during the DW and were non-compliant just looked to see if there was any conflicting traffic before departing, and the delay time was minimal.

Pedestrian Walking Speed

To get a basic idea of the effect of pedestrian countdown timers on pedestrian walking speed, the average walking speed was calculated before and after installation, and is presented in Table 9.

Table 9: Pedestrian Walking Speed

	Average Walking Speed (ft/sec)
Before	4.8
After	5.0

As seen in Table 9, the overall difference in walking speed before and after installation is 0.2 ft/sec. To see if pedestrian countdown timers had a significant effect on pedestrian walking speed, linear regression modeling was used. As mentioned earlier, a transparency, taped on top of a computer screen, was used to determine the exact times that pedestrians arrived at 10 ft increments while crossing. Walking speed was calculated for each 10 ft section, and walking speed for each section was used as the dependent variable. The independent variables used include:

- The 10 ft section that the pedestrian was walking in, based on the distance from the point of crosswalk entry (Dummy)

- Five minute conflicting traffic (Integer)
- Day of week (Dummy)
- Time of day (Dummy)
- Pedestrian compliance (Dummy)
- Presence of a car stopped on G St (Dummy)
- Presence of another pedestrian inside the crosswalk (Dummy)
- Phase that the pedestrian arrived during: WALK, FDW, or DW (Dummy)
- Delay time, sec, measured from time of arrival to time of departure (Decimal)
- Direction of travel (Dummy)
- Presence of pedestrian countdown timers (Dummy)

A complete list of all variables is listed in Appendix A. Linear regression was used to model the pedestrian walking speed. The simple linear regression model is as follows (20):

$Y_i = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + ... + \beta_j \cdot X_j + ... + \beta_n \cdot X_n + \varepsilon_i$, where:

Y_i = Estimated value of dependent variable during observation i,

β = Estimated coefficient of independent variable,

n = number of independent variables,

X = Value of independent variable j during observation i, and

ε = Disturbance term, normally distributed with mean = 0 and variance = σ^2

Ordinary least squares regression was used to minimize the disturbance. Table 10 lists the results of the pedestrian walking speed model.

Table 10: Pedestrian Walking Speed Model

Linear Regression		
Dependent Variable: Pedestrian Walking Speed, ft/sec		
Number of observations: 5816		
Unrestricted Log Likelihood = -1743.324		
Restricted Log Likelihood = -1792.191		
AIC = -0.425		
Mean = 4.856	Std dev = 0.830	
R^2 = 0.065		
Variable Name (Type)	**Estimated Coefficient**	**t-stats**
Constant	4.814	152.608
Presence of car stopped on G St (Dummy)	0.152	2.596
Presence of another pedestrian (Dummy)	-0.163	-3.530
Arrives on FDW and doesn't stop (Dummy)	0.269	4.021
Delay time (Decimal)	-0.019	-4.751
Presence of pedestrian countdown timer (Dummy)	0.177	3.775

This model shows many statistically significant variables at 95% confidence, including the presence of a car stopped on G St, presence of another pedestrian inside of the crosswalk, arrives on FDW and doesn't stop, delay time (s), and the presence of pedestrian countdown timers. Because the estimated coefficient of the presence of pedestrian countdown timers variable is positive in the model, pedestrian countdown timers statistically significantly increased pedestrian walking speed. The estimated coefficient is approximately 0.2, meaning that pedestrians walked approximately 0.2 ft/sec faster after pedestrian countdown timers were installed, which does not have much of a physical meaning. None of the 10 ft sections were statistically significant, indicating that the pedestrians had a consistent walking speed throughout their trip.

The results of the pedestrian walking speed model indicate that when a car is stopped on G St, pedestrian walking speed is significantly higher than when there are no cars stopped on G St. In addition, pedestrian walking speed decreases when there are multiple pedestrians in the crosswalk. Interestingly, the model shows that pedestrian walking speed decreases when delay time increases. This could be due to the time it takes for pedestrians to get up to their normal walking speed. For the pedestrians who experienced some delay time, it was common for them to stop and wait right on the curb. This led to a slight acceleration time in which they started to cross at a slower speed but then reached their normal walking speed after a few steps. However, since there were not many pedestrians who experienced delay time, the first 10 ft section did not have a significantly slower walking speed than any other 10 ft section.

Driver Data Analysis Results

Probability of Stopping

When a driver approaches an intersection, the driver is forced to make a decision on whether to go through the intersection, or come to a stop, at the onset of yellow. A probit model, a type of binary discrete choice statistical model, can model the driver's decision. According to Sheffi & Mahmassani (18), the sample size required for estimating dilemma zone boundaries is significantly reduced when using a probit model to model the driver's decision. The result of the probit model is a probability of stopping curve that gives the probability of a driver choosing to stop at the intersection given the vehicle's distance from the stop bar at the onset of yellow at a certain speed. Using the probability of stopping curve, dilemma zone boundaries can be determined. According to Zegeer (21), the dilemma zone is a range of distances from the stop bar, beginning at a distance where 10% of vehicles stop, and ending at a distance where 90% of vehicles stop, where drivers are forced to make a decision to either stop or go through the intersection at the onset of yellow. The length of the dilemma zone is calculated as the difference between the dilemma zone boundaries.

Following the methodology developed by Sheffi & Mahmassani (18), Sharma (16), and Burnett (3), a probit model was developed to determine the probability of stopping of a single vehicle approaching an intersection. The dependent variable was a dummy variable corresponding to either the vehicle proceeding through the intersection (0) or the vehicle coming to a stop (1). Example independent variables included in the model were:

- High temperature, °F (Integer)
- Day of week (Dummy)
- Time of day (Dummy)
- Time to stop bar assuming the vehicle traveled at a constant speed equal to the speed it was going at the onset of yellow (Decimal)
- Amount of acceleration required for the vehicle to proceed through the intersection during the yellow phase (Decimal)
- Amount of deceleration required for the vehicle to stop at the stop bar (Decimal)

- 15 min. volume of traffic on 17th St (Integer)
- Presence of a pedestrian waiting to cross 17th St (Dummy)
- Lane (Dummy)
- Presence of pedestrian countdown timers (Dummy)

A complete list of variables is listed in Appendix A. Three separate probit models were developed, one before installation, one after installation, and one with all data combined from before and after installation of pedestrian countdown timers.

S 17th St and G St

The probit models for probability of stopping at S 17th St & G St are presented in Tables 11 and 12.

Table 11: Probit Model Before Installation of PCT at S 17th St and G St

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 429		
Unrestricted Log Likelihood: -98.183	Restricted Log Likelihood: -292.107	
Prob(X^2)>value = 0.000	AIC value: 0.467	McFadden R^2 = 0.664
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.55	4.343
Required Acceleration (Decimal)	0.108	10.496

Table 12: Probit Model After Installation of PCT at S 17th St and G St

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 422		
Unrestricted Log Likelihood: -62.399	Restricted Log Likelihood: -292.489	
Prob(X^2)>value = 0.000	AIC value: 0.305	McFadden R^2 = 0.787
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.7	4.676
Required Acceleration (Decimal)	0.132	9.309

Developed by using the probit models presented in Tables 11 and 12, Figure 18 shows the probability of stopping curves before and after installation of pedestrian countdown timers at S 17th St and G St.

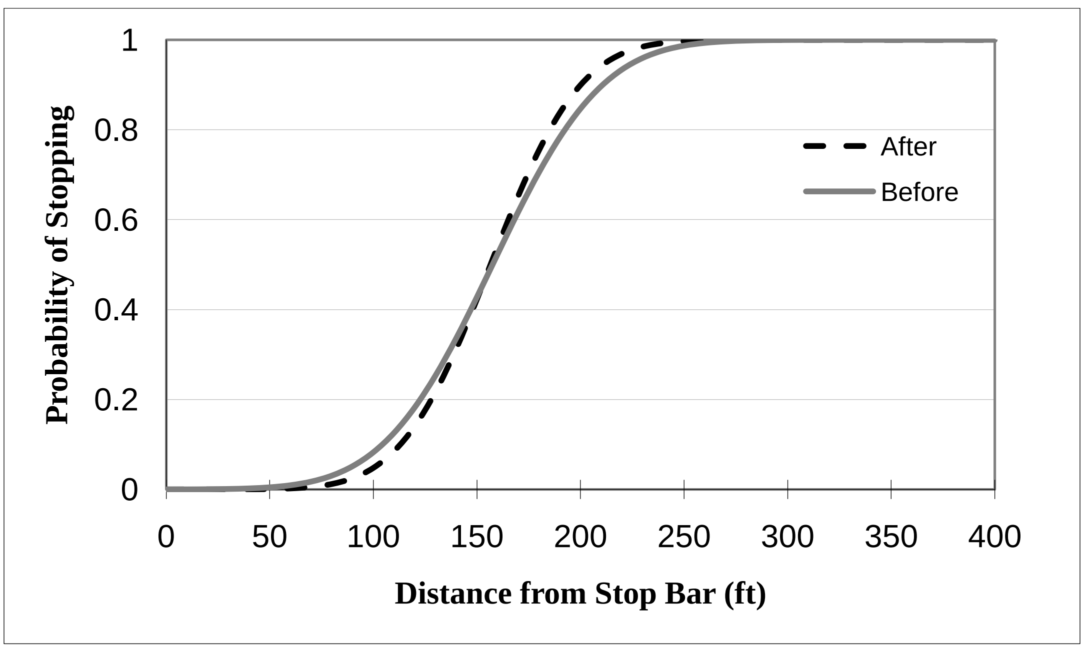


Figure 18: Probability of Stopping at S 17th St and G St

It can be seen in Figure 18 that the probability of stopping curve became steeper after installation of pedestrian countdown timers. The steeper curve results in shifted dilemma zone boundaries. Table 13 shows the dilemma zone boundaries before and after installation of pedestrian countdown timers at S 17th St and G St.

Table 13: Dilemma Zone Boundaries at S 17th St and G St

	Distance from Stop Bar (ft)		
	Begin Dilemma Zone	End Dilemma Zone	Length of Dilemma Zone (ft)
Before	104	211	107
After	113	200	87

The dilemma zone is shortened after installation of pedestrian countdown timers at S 17th St and G St by 20 ft. This improves safety because there is less of an area where vehicles could be caught in the dilemma zone. In addition, at S 17th St & G St, the number of red light runners reduced after installation of pedestrian countdown timers. Before installation, 10 vehicles out of 429 vehicles (2.3%) ran the red light. After installation, only 3 vehicles out of 422 vehicles (0.7%) ran the red light. This also leads to an improvement in safety. A third probit model was developed that contained all data, to determine if the presence of pedestrian countdown timers significantly affects the probability of stopping curve. Table 14 lists the results of the combined model.

Table 14: Probit Model of Combined Data at S 17th St and G St

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 851		
Unrestricted Log Likelihood: -161.554	Restricted Log Likelihood: -586.903	
Prob(X^2)>value = 0.000 AIC value: 0.387 McFadden R^2 = 0.725		
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.622	5.143
Required Acceleration (Decimal)	0.118	14.181
Presence of Pedestrian Countdown Timers (Dummy)	-0.004	-0.023

The addition of the pedestrian countdown timers did not statistically significantly affect the probability of stopping model. The alternate hypothesis, that pedestrian countdown timers have a significant effect on probability of stopping curve, is rejected. After testing multiple other models, no other independent variables showed up as significant, therefore the increased slope in the probability of stopping curves and the shift in dilemma zone boundaries may be attributed to pedestrian countdown timers, but it is not statistically significant.

27th St and Cornhusker Highway

The probit models for probability of stopping at 27th St and Cornhusker Highway are presented in Tables 15 and 16.

Table 15: Probit Model Before Installation of PCT at 27th St and Cornhusker Highway

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 525		
Unrestricted Log Likelihood: -150.891	Restricted Log Likelihood: -341.877	
$Prob(X^2)$>value = 0.000	AIC value: 0.582	McFadden R^2 = 0.559
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.354	3.878
Required Acceleration (Decimal)	0.100	12.216

Table 16: Probit Model After Installation of PCT at 27th St and Cornhusker Highway

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 482		
Unrestricted Log Likelihood: -135.999	Restricted Log Likelihood: -302.721	
$Prob(X^2)$>value = 0.000	AIC value: 0.573	McFadden R^2 = 0.551
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.315	3.271
Required Acceleration (Decimal)	0.113	11.400

Developed by using the probit models presented in Tables 15 and 16, Figure 19 shows the probability of stopping curves before and after installation of pedestrian countdown timers at 27th St and Cornhusker Highway. Table 17 shows the dilemma zone boundaries before and after installation of pedestrian countdown timers at 27th St and Cornhusker Highway.

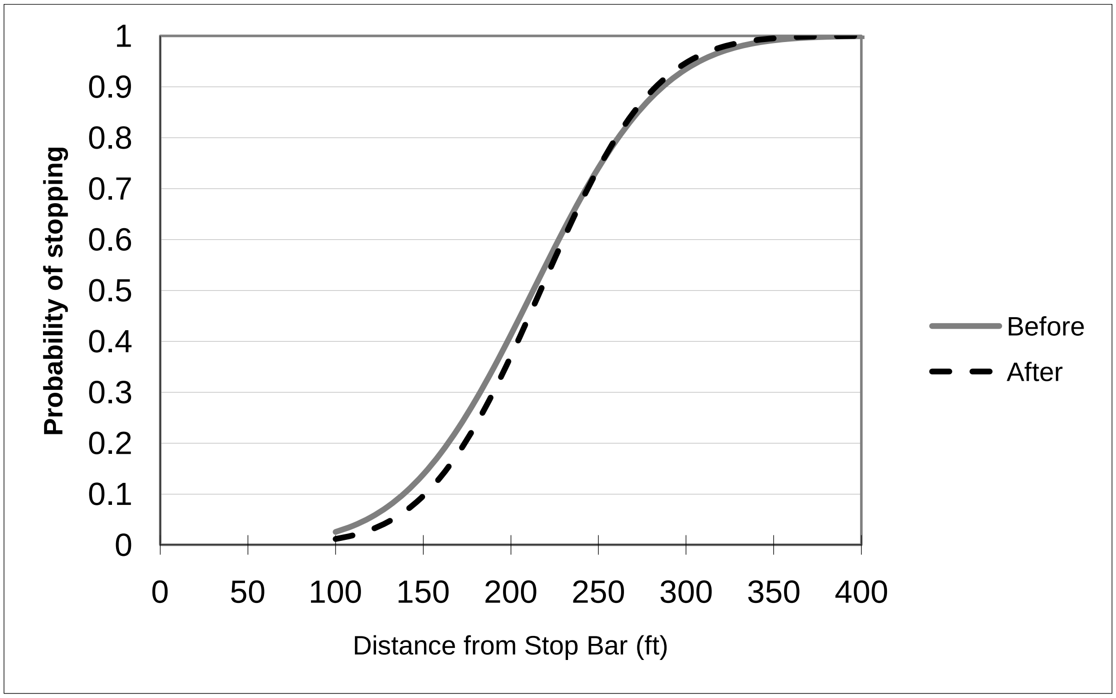


Figure 19: Probability of Stopping at 27th St and Cornhusker Highway

Similar to the results found at 17th St & G St, it can be seen in Figure 19 that the probability of stopping curve became steeper after installation of pedestrian countdown timers at 27th St & Cornhusker Hwy. The steeper curve results in shifted dilemma zone boundaries. Table 17 shows the dilemma zone boundaries before and after installation of pedestrian countdown timers at S 17th St and G St.

Table 17: Dilemma Zone Boundaries at 27th St and Cornhusker Highway

	Distance from Stop Bar (ft)		
	Begin Dilemma Zone	End Dilemma Zone	Length of Dilemma Zone (ft)
Before	138	287	149
After	151	283	132

Table 17 shows that the length of the dilemma zone is reduced by about 17 ft after installation of pedestrian countdown timers, which improves safety. At 27th St &

Cornhusker Hwy, approximately the same amount of vehicles ran the red light before and after installation. Before installation, 7 vehicles out of 525 vehicles (1.3%) ran the red light, and after installation, 8 vehicles out of 482 vehicles (1.6%) ran the red light. To test if pedestrian countdown timers have a significant effect on the probability of stopping, an overall probit model was developed, and is presented in Table 18.

Table 18: Probit Model of Combined Data at 27th St and Cornhusker Highway

Probability of Stopping Model		
Dependent Variable: Vehicles Goes or Stops (Goes = 0 / Stops = 1)		
Number of Observations: 1007		
Unrestricted Log Likelihood: -287.359		Restricted Log Likelihood: -645.270
Prob(X^2)>value = 0.000 AIC value: 0.577 McFadden R^2 = 0.555		
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	0.380	4.295
Required Acceleration (Decimal)	0.106	16.733
Presence of Pedestrian Countdown Timers (Dummy)	-0.095	-0.805

The addition of the pedestrian countdown timer did not statistically significantly affect the probability of stopping model. The alternate hypothesis that pedestrian countdown timers have a significant effect on probability of stopping is rejected.

Speed at the Stop Bar of Vehicles during Yellow Phase

S 17th St and G St

To see the effects that pedestrian countdown timers have on vehicle speeds, the speed at the stop bar of vehicles during the yellow phase was studied. All vehicles that passed through the intersection during the yellow phase were included. Figure 20 shows the relative frequency of speed at the stop bar of vehicles during the yellow phase at S 17th & G, before and after installation of pedestrian countdown timers. Figure 21 shows the cumulative distribution function (CDF) of speed at the stop bar, normally distributed, at 17th & G, before and after installation of pedestrian countdown timers.

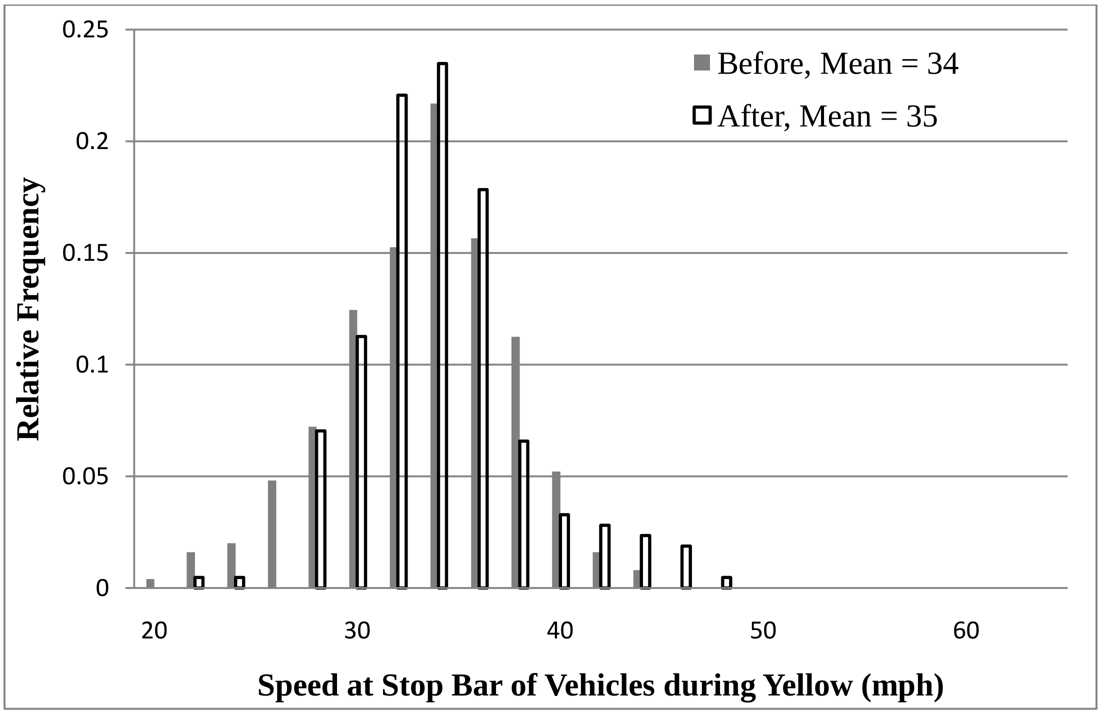


Figure 20: Relative Frequency of Speed at Stop Bar of Vehicles during the Yellow Phase at 17th & G

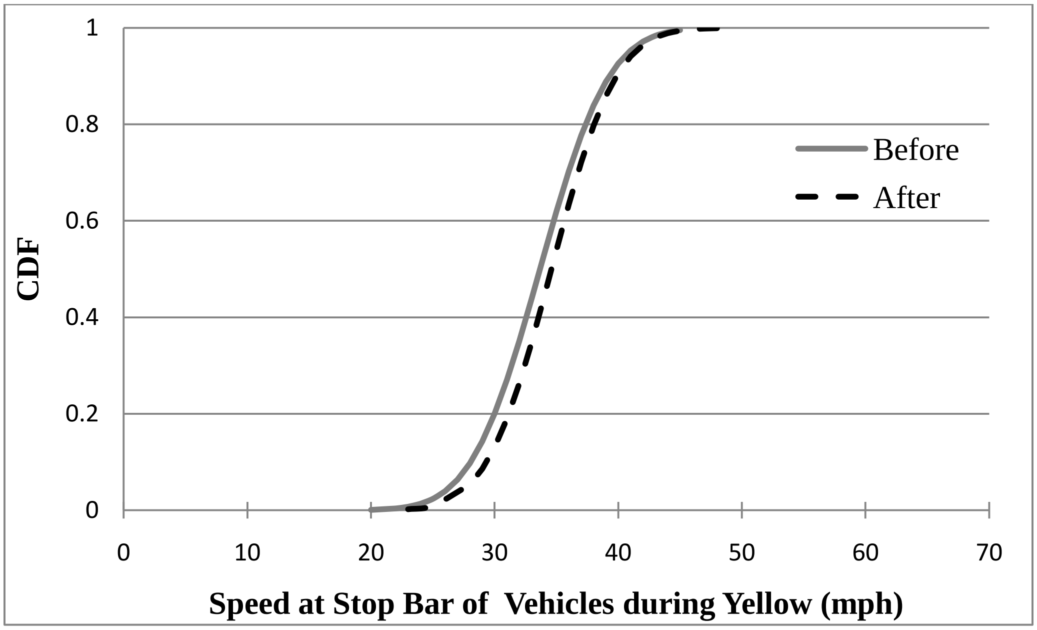


Figure 21: Cumulative Distribution Function of Speed at Stop Bar of Vehicles during the Yellow Phase at 17th & G

Linear regression was used to model the speed at the stop bar of vehicles during the yellow phase. The dependent variable in the model was the speed of vehicle (mi/hr) at the stop bar. The independent variables were the same as the probability of stopping probit model, with the addition of the vehicle's speed at the onset of yellow (see Appendix A for a complete list of independent variables). One overall model was used to determine if pedestrian countdown timers have an effect on speed at the stop bar of vehicles during the yellow phase at each intersection. Table 19 lists the results of the vehicle speed at stop bar model at S 17th St and G St.

Table 19: Speed at Stop Bar of Vehicles during Yellow Phase Model at S 17th St and G St

Ordinary Least Squares Regression		
Dependent Variable: Speed of Vehicle at Stop Bar, mi/hr (Integer)		
Number of observations: 408		
Unrestricted Log Likelihood = -854.575	Restricted Log Likelihood = -1079.257	
AIC = 1.371		R^2 = 0.668
Prob(X2)>value = 0.000		Adjusted R^2 = 0.665
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	7.835	8.098
Time to stop bar (Decimal)	0.569	5.766
Speed at onset of yellow (Integer)	0.758	28.322
Presence of pedestrian countdown timers (Dummy)	0.110	0.563

The alternate hypothesis that pedestrian countdown timers have a significant effect on speed at the stop bar of vehicles during the yellow phase is rejected at S 17th St and G St.

27th St and Cornhusker Highway

Figures 22 and 23 show the relative frequency of speeds at the stop bar, and the cumulative distribution function (CDF) of speed at the stop bar normally distributed, at 27th & Cornhusker Highway, before and after installation of pedestrian countdown timers.

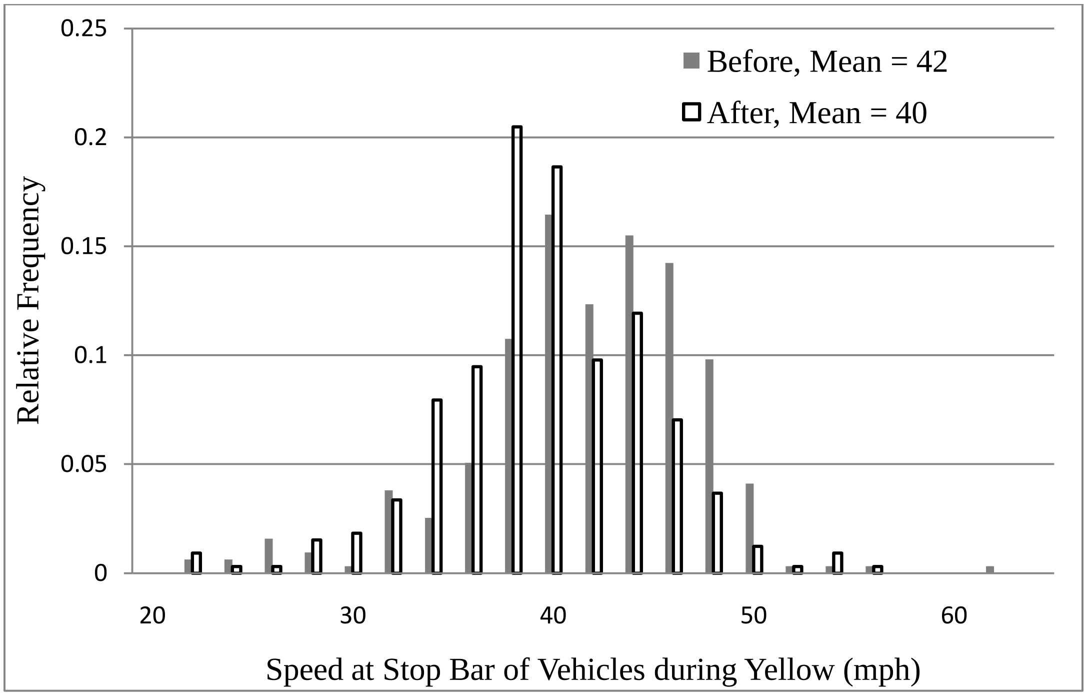


Figure 22: Relative Frequency of Speed at Stop Bar of Vehicles during the Yellow Phase at 27th St & Cornhusker Highway

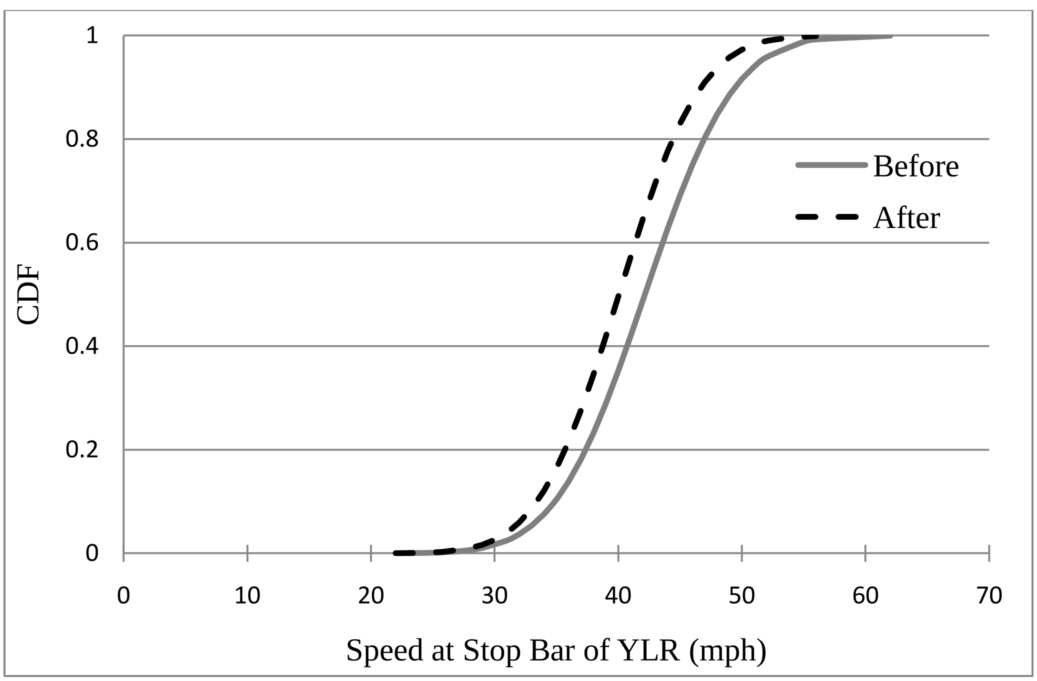


Figure 23: Cumulative Distribution Function of Speed at Stop Bar of Vehicles during the Yellow Phase at 27th St & Cornhusker Highway

Table 20 lists the results of the vehicle speed at stop bar model at 27th St and Cornhusker Highway.

Table 20: Speed at Stop Bar of Vehicles during Yellow Phase Model at 27th St and Cornhusker Highway

Ordinary Least Squares Regression		
Dependent Variable: Speed of Vehicle at Stop Bar, mi/hr (Integer)		
Number of observations: 620		
Unrestricted Log Likelihood = -1540.039		Restricted Log Likelihood = -1852.579
AIC = 2.143		R^2 = 0.635
Prob(X2)>value = 0.000		Adjusted R^2 = 0.633
Variable Name (Type)	**Estimated Coefficient**	**T-stats**
Constant	13.338	13.880
Time to stop bar (Decimal)	0.676	7.042
Speed at onset of yellow (Integer)	0.659	30.914
Presence of pedestrian countdown timers (Dummy)	-1.016	-4.269

Pedestrian countdown timers have a significant effect on speed at the stop bar of vehicles during the yellow phase at 27th St and Cornhusker Highway. Pedestrian countdown timers significantly decrease the speed at the stop bar of vehicles during the yellow phase by 1.0 mi/hr. This is opposite of the alternate hypothesis that speed at the stop bar of vehicles during the yellow phase would increase after installation of pedestrian countdown timers.

The calculated t-statistic is -4.873 for a simple two-sample t-test of the mean speed at stop bar, which is significant at 95% confidence. It can be seen in Figure 25 that the relative frequencies of speed shift to the left. Similarly, it can be seen in Figure 26 that the CDF shifts to the left after installation of pedestrian countdown timers. The difference in the CDF curves is greater as speed increases. Since no other variables came up to be significant in the linear regression model presented in Table 25, the difference in speeds at the stop bar of vehicles during the yellow phase can be attributed to pedestrian countdown timers.

Summary of Findings

At S 17th St & G St, pedestrian countdown timers statistically significantly increased pedestrian walking speed by 0.2 ft/sec. Pedestrian countdown timers did not significantly affect pedestrian compliance, probability of stopping, or the speed of vehicles at the stop bar during the yellow phase at the S 17th St & G St intersection. At 27th St & Cornhusker Highway, pedestrian countdown timers significantly reduced vehicle speeds at the stop bar during the yellow phase by 1.0 mi/hr, which was contrary to the hypothesis that vehicle speeds would increase after installation of pedestrian countdown timers. Pedestrian countdown timers did not significantly affect probability of stopping at 27th St & Cornhusker Hwy. Table 21 lists the effects of pedestrian countdown timers at both intersections on safety and efficiency of operations.

Table 21: Effects of Pedestrian Countdown Timers on Safety and Efficiency of Operations

Performance Measure	Effect of Pedestrian Countdown Timers	Significant at 17th and G (95% Confidence)	Significant at 27th and Cornhusker (95% Confidence)	Physical Amount of Effect
Pedestrian Compliance	Increase in pedestrian compliance	No	Not Tested	None
Pedestrian Walking Speed	Increase in pedestrian walking speed	Yes	Not Tested	0.2 ft/sec
Probability of Stopping	Steeper Probability of Stopping Curve	No	No	None
Speed at Stop Bar of Vehicles during Yellow Phase	Decreased speed at stop bar of vehicles during yellow phase	No	Yes	-1.0 mi/hr

The results shown in Table 21 closely resemble the results of the hypotheses tested, with the exception of the speed at the stop bar of vehicles during the yellow phase at 27^{th} St & Cornhusker Hwy. Table 22 lists the performance measure, hypotheses tested, and whether the hypotheses were verified for both intersections.

Table 22: Hypothesis Verification

Performance Measure	Hypothesis (After Installation of PCT)	Hypothesis Verified at 17th and G	Hypothesis Verified at 27th and Cornhusker
Pedestrian Compliance	Pedestrian compliance will increase	No	Not Tested
Pedestrian Walking Speed	Pedestrian walking speed will increase	Yes	Not Tested
Probability of Stopping	Probability of stopping curve will become steeper	No	No
Speed at Stop Bar of Vehicles during Yellow Phase	Speed at the stop bar will increase	No	No

In Table 22, the hypothesis was verified if the effect of pedestrian countdown timers was statistically significant and was the same as the hypothesis tested. The hypothesis was not verified if the effect was not statistically significant. The only result that was opposite of the hypothesis was the speed at the stop bar of vehicles during the yellow phase at 27th St & Cornhusker Hwy. It was hypothesized that speed would increase after installation of pedestrian countdown timers, which was opposite of the finding that speeds decreased after installation.

Chapter 5 - Conclusions

In this thesis, a case study was performed at two intersections in Lincoln, NE: S 17th St & G St and 27th St & Cornhusker Highway, testing the effects of pedestrian countdown timers on safety and efficiency of operations. The effects were found using innovative microscopic analysis, by using statistical modeling tools. The statistical modeling tools determined the precise effects that pedestrian countdown timers had on safety and efficiency. The effects of pedestrian countdown timers on safety are a slightly, but not statistically significant, steeper probability of stopping curve, which improves safety. The effects of pedestrian countdown timers on efficiency of operations are, from a pedestrian analysis perspective, a significant increase in pedestrian walking speed, and from a driver analysis perspective, a significant decrease of speed at the stop bar of vehicles during the yellow phase. The increase in pedestrian walking speed is a desirable effect because it increases efficiency of pedestrians. The reduction in speed at the stop bar of vehicles during the yellow phase decreases efficiency of operations. Overall, the conclusions to this study are as follows: pedestrian countdown timers increase safety, increase pedestrian efficiency, and decrease vehicle efficiency of operations at signalized intersections.

The effects that pedestrian countdown timers had on safety and efficiency of operations were different at the two intersections studied, which concurs with past research that found contradictory results at different intersections within the same city. Therefore, pedestrian countdown timers were found to have site-specific effects on safety and efficiency. Further research is needed to determine the causes of the site-specific effects. If the causes of the site-specific effects can be determined, recommendations can be made about where it may be beneficial to install pedestrian countdown timers, and where pedestrian countdown timers may not benefit the intersection. However, it may still be necessary to calculate the site-specific benefit to cost ratio before recommending installation of pedestrian countdown timers.

References

1. Arhin, S. A., & Noel, E. C. (2007). Impact of countdown pedestrian signals on pedestrian behavior and perception of intersection safety in the District of Columbia. *Intelligent Transportation Systems Conference*, 337-342.
2. Botha, J., Zabyshny, A., Day, J., Northouse, R., Rodriguez, J., & Nix, T. (2002, May). *Pedestrian Countdown Signals: An Experimental Evaluation*. San Jose State University & City of San Jose Department of Transportation Final Report to the California Traffic Control Devices Committee.
3. Burnett, N. (2011). Effect of Information on Driver's Risk at the Onset of Yellow at High-Speed Intersections (Master's Thesis, University of Nebraska-Lincoln, 2011).
4. Eccles, K. A., Tao, R., & Mangum, B. C. (2003). Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland. *Transportation Research Board CD-ROM*
5. Hauer, E. (1997). *Observational Before-After Studies in Road Safety*. Terrytown, New York: Pergamon Press.
6. He, Y., Zhang, J., Sun, X., & Wei, R. (2009). Investigating Road Users' Preference on Signal Countdown Devices at Intersections in Beijing. *Transportation Research Board CD-ROM*
7. Huang, H., & Zegeer, C. (2000). *The effects of pedestrian countdown signals in Lake Buena Vista*. Florida Department of Transportation.
8. Huey, S. B., & Ragland, D. (2007). Changes in driver behavior resulting from pedestrian countdown signals. *Transportation Research Board CD-ROM*

9. Kim, K. W., Kim, Y., & Seo, H. Y. (2002). An evaluation of pedestrian countdown signals. *KSCE Journal of Civil Engineering*, *6*(4), 533-537.

10. Limanond, T., Chookerd, S., & Roubtonglang, N. (2009). Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection. *Transportation Research Part C, 17*, 662-671.

11. Ma, W., Wu, Z., & Yang, X. (2008). Empirical Analysis of Pedestrian Countdown Signals in Shanghai: A Case Study. *Transportation Research Board CD-ROM.*

12. Markowitz, F., Sciortino, S., Fleck, J. L., & Yee, B. M. (2006). Pedestrian countdown signals: Experience with an extensive pilot installation. *ITE Journal, 76*(1), 43-48.

13. Perkins, S., & Harris, J. (1968). Traffic conflict characteristics - accident potential at intersections. *Highway Research Record*, *225*, 35-43.

14. Schattler, K., Wakim, J., Datta, T., & McAvoy, D. (2007). Evaluation of pedestrian and driver behaviors at countdown pedestrian signals in Peoria, Illinois. *Transportation Research Record, 2002*(98), 106.

15. Schrock, S. D., & Bundy, B. (2008). Pedestrian Countdown Timers: Do Drivers Use Them to Increase Safety or Increase Risk Taking?. *Transportation Research Board CD-ROM*

16. Sharma, A. (2008). Integrated behavioral and economic framework for improving dilemma zone protection systems. Purdue University, West Lafayette, IN.

17. Sharma, A., Vanajakshi, L., & Rao, N. (2009). Effect of phase countdown timers on queue discharge characteristics under heterogeneous traffic conditions. *Transportation Research Record,* (Accepted for Publication 2009)

18. Sheffi, Y., and M. Mahmassani. (1981). A Model of Driver Behavior at High Speed Signalized Intersections, *Transportation Science*, Vol. 15, pp. 51-61.

19. Washburn, S., Leistner, D., & Ko, B. (2007). An evaluation of the effectiveness of pedestrian countdown signals. In K. G. Goulias (Ed.), Transport science and technology (1st ed., pp. 311-326). Oxford, UK: Elsevier.

20. Washington, S., Karlaftis, M., & Mannering, F. (2003). *Statistical and Econometric Methods for Transportation Data Analysis.* Boca Raton, FL: Chapman & Hall/CRC.

21. Zegeer, C. (1977). Effectiveness of green-extension systems at high-speed intersections. *Research Report 472*, Bureau of Highways, Kentucky Department of Transportation, Lexington, KY.

22. Greene, W. (2007). *NLOGIT 4.0: User's Guide.* Econometric Software, Inc. Plainview, NY.

23. Akaike, Hirotugu (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control, 19*(6), 716-723.

24. Nambisan, S., & Karkee, G. (2010). Do pedestrian countdown signals influence vehicle speeds? *Transportation Research Record, 2149*. 70-76.

25. Sharma, A., Bullock, D., & Peeta, S. (2011). Estimating dilemma zone hazard function at high speed isolated intersection. *Transportation Research Part C, 19*(3). 400-412

Appendix A – Variables Used in Statistical Models

Variables Used in Pedestrian Compliance Model

Variable	Description	Type	Coding
X1	Pedestrian Violation	Dependent	Dummy Variable 1/0
X2	Conflicting 5 min Traffic Volume on G St	Independent	Integer
X3	S 17th St 5 min Right Turning Volume	Independent	Integer
X4	Maximum Daily Outside Temperature (°F)	Independent	Integer
X5	Sunday	Independent	Dummy Variable 1/0
X6	Monday	Independent	Dummy Variable 1/0
X7	Tuesday	Independent	Dummy Variable 1/0
X8	Wednesday	Independent	Dummy Variable 1/0
X9	Thursday	Independent	Dummy Variable 1/0
X10	Friday	Independent	Dummy Variable 1/0
X11	Saturday	Independent	Dummy Variable 1/0
X12	Midnight to 1 a.m.	Independent	Dummy Variable 1/0
X13	1 a.m. to 2 a.m.	Independent	Dummy Variable 1/0
X14	2 a.m. to 3 a.m.	Independent	Dummy Variable 1/0
X15	3 a.m. to 4 a.m.	Independent	Dummy Variable 1/0
X16	4 a.m. to 5 a.m.	Independent	Dummy Variable 1/0
X17	5 a.m. to 6 a.m.	Independent	Dummy Variable 1/0
X18	6 a.m. to 7 a.m.	Independent	Dummy Variable 1/0
X19	7 a.m. to 8 a.m.	Independent	Dummy Variable 1/0
X20	8 a.m. to 9 a.m.	Independent	Dummy Variable 1/0
X21	9 a.m. to 10 a.m.	Independent	Dummy Variable 1/0
X22	10 a.m. to 11 a.m.	Independent	Dummy Variable 1/0
X23	11 a.m. to noon	Independent	Dummy Variable 1/0
X24	Noon to 1 p.m.	Independent	Dummy Variable 1/0
X25	1 p.m. to 2 p.m.	Independent	Dummy Variable 1/0
X26	2 p.m. to 3 p.m.	Independent	Dummy Variable 1/0
X27	3 p.m. to 4 p.m.	Independent	Dummy Variable 1/0
X28	4 p.m. to 5 p.m.	Independent	Dummy Variable 1/0
X29	5 p.m. to 6 p.m.	Independent	Dummy Variable 1/0
X30	6 p.m. to 7 p.m.	Independent	Dummy Variable 1/0
X31	7 p.m. to 8 p.m.	Independent	Dummy Variable 1/0
X32	8 p.m. to 9 p.m.	Independent	Dummy Variable 1/0
X33	9 p.m. to 10 p.m.	Independent	Dummy Variable 1/0
X34	10 p.m. to 11 p.m.	Independent	Dummy Variable 1/0
X35	11 p.m. to midnight	Independent	Dummy Variable 1/0
X36	Walking Speed (ft/sec)	Independent	Real Number
X37	Presence of Car Stopped on G St	Independent	Dummy Variable 1/0
X38	Presence of Another Pedestrian Inside Crosswalk	Independent	Dummy Variable 1/0

X39	Arrive on DW	Independent	Dummy Variable 1/0
X40	Arrive on FDW	Independent	Dummy Variable 1/0
X41	Arrive on WALK	Independent	Dummy Variable 1/0
X42	Delay Time (s)	Independent	Real Number
X43	Pedestrian Traveling from North to South	Independent	Dummy Variable 1/0
X44	Presence of Pedestrian Countdown Timer	Independent	Dummy Variable 1/0

Variables Used in Pedestrian Walking Speed Model

Variable	Description	Type	Coding
X1	Walking Speed (ft/sec)	Dependent	Real Number
X2	Conflicting 5 min Traffic Volume on G St	Independent	Integer
X3	S 17th St 5 min Right Turning Volume	Independent	Integer
X4	Maximum Daily Outside Temperature (°F)	Independent	Integer
X5	Sunday	Independent	Dummy Variable 1/0
X6	Monday	Independent	Dummy Variable 1/0
X7	Tuesday	Independent	Dummy Variable 1/0
X8	Wednesday	Independent	Dummy Variable 1/0
X9	Thursday	Independent	Dummy Variable 1/0
X10	Friday	Independent	Dummy Variable 1/0
X11	Saturday	Independent	Dummy Variable 1/0
X12	Midnight to 1 a.m.	Independent	Dummy Variable 1/0
X13	1 a.m. to 2 a.m.	Independent	Dummy Variable 1/0
X14	2 a.m. to 3 a.m.	Independent	Dummy Variable 1/0
X15	3 a.m. to 4 a.m.	Independent	Dummy Variable 1/0
X16	4 a.m. to 5 a.m.	Independent	Dummy Variable 1/0
X17	5 a.m. to 6 a.m.	Independent	Dummy Variable 1/0
X18	6 a.m. to 7 a.m.	Independent	Dummy Variable 1/0
X19	7 a.m. to 8 a.m.	Independent	Dummy Variable 1/0
X20	8 a.m. to 9 a.m.	Independent	Dummy Variable 1/0
X21	9 a.m. to 10 a.m.	Independent	Dummy Variable 1/0
X22	10 a.m. to 11 a.m.	Independent	Dummy Variable 1/0
X23	11 a.m. to noon	Independent	Dummy Variable 1/0
X24	Noon to 1 p.m.	Independent	Dummy Variable 1/0
X25	1 p.m. to 2 p.m.	Independent	Dummy Variable 1/0
X26	2 p.m. to 3 p.m.	Independent	Dummy Variable 1/0
X27	3 p.m. to 4 p.m.	Independent	Dummy Variable 1/0
X28	4 p.m. to 5 p.m.	Independent	Dummy Variable 1/0
X29	5 p.m. to 6 p.m.	Independent	Dummy Variable 1/0

X30	6 p.m. to 7 p.m.	Independent	Dummy Variable 1/0
X31	7 p.m. to 8 p.m.	Independent	Dummy Variable 1/0
X32	8 p.m. to 9 p.m.	Independent	Dummy Variable 1/0
X33	9 p.m. to 10 p.m.	Independent	Dummy Variable 1/0
X34	10 p.m. to 11 p.m.	Independent	Dummy Variable 1/0
X35	11 p.m. to midnight	Independent	Dummy Variable 1/0
X36	Violation	Independent	Dummy Variable 1/0
X37	Presence of Car Stopped on G St	Independent	Dummy Variable 1/0
X38	Presence of Another Pedestrian Inside Crosswalk	Independent	Dummy Variable 1/0
X39	Arrive on DW	Independent	Dummy Variable 1/0
X40	Arrive on DW & Doesn't Stop	Independent	Dummy Variable 1/0
X41	Arrive on DW, Pauses, and Goes on DW	Independent	Dummy Variable 1/0
X42	Arrive on DW & Wait for WALK	Independent	Dummy Variable 1/0
X43	Arrive on FDW	Independent	Dummy Variable 1/0
X44	Arrive on FDW & Doesn't Stop	Independent	Dummy Variable 1/0
X45	Arrive on FDW, Pauses, and Goes on DW	Independent	Dummy Variable 1/1
X46	Arrive on FDW & Wait for WALK	Independent	Dummy Variable 1/2
X47	Arrive on FDW, Goes, and Finishes Before DW Starts	Independent	Dummy Variable 1/3
X48	Arrive on WALK	Independent	Dummy Variable 1/4
X49	Delay Time (s)	Independent	Real Number
X50	Pedestrian Traveling from North to South	Independent	Dummy Variable 1/0
X51	Presence of Pedestrian Countdown Timer	Independent	Dummy Variable 1/0
X52	Pedestrian in Section 1	Independent	Dummy Variable 1/0
X53	Pedestrian in Section 2	Independent	Dummy Variable 1/0
X54	Pedestrian in Section 3	Independent	Dummy Variable 1/0
X55	Pedestrian in Section 4	Independent	Dummy Variable 1/0

Variables Used in Probability of Stopping Model

Variable	Description	Type	Coding
X1	Proceed through (0) or stop (1)	Dependent	Dummy Variable 1/0
X2	Maximum Daily Outside Temperature (°F)	Independent	Integer
X3	Sunday	Independent	Dummy Variable 1/0
X4	Monday	Independent	Dummy Variable 1/0
X5	Tuesday	Independent	Dummy Variable 1/0
X6	Wednesday	Independent	Dummy Variable 1/0
X7	Thursday	Independent	Dummy Variable 1/0
X8	Friday	Independent	Dummy Variable 1/0
X9	Saturday	Independent	Dummy Variable 1/0
X10	Midnight to 1 a.m.	Independent	Dummy Variable 1/0
X11	1 a.m. to 2 a.m.	Independent	Dummy Variable 1/0
X12	2 a.m. to 3 a.m.	Independent	Dummy Variable 1/0
X13	3 a.m. to 4 a.m.	Independent	Dummy Variable 1/0
X14	4 a.m. to 5 a.m.	Independent	Dummy Variable 1/0
X15	5 a.m. to 6 a.m.	Independent	Dummy Variable 1/0
X16	6 a.m. to 7 a.m.	Independent	Dummy Variable 1/0
X17	7 a.m. to 8 a.m.	Independent	Dummy Variable 1/0
X18	8 a.m. to 9 a.m.	Independent	Dummy Variable 1/0
X19	9 a.m. to 10 a.m.	Independent	Dummy Variable 1/0
X20	10 a.m. to 11 a.m.	Independent	Dummy Variable 1/0
X21	11 a.m. to noon	Independent	Dummy Variable 1/0
X22	Noon to 1 p.m.	Independent	Dummy Variable 1/0
X23	1 p.m. to 2 p.m.	Independent	Dummy Variable 1/0
X24	2 p.m. to 3 p.m.	Independent	Dummy Variable 1/0
X25	3 p.m. to 4 p.m.	Independent	Dummy Variable 1/0
X26	4 p.m. to 5 p.m.	Independent	Dummy Variable 1/0
X27	5 p.m. to 6 p.m.	Independent	Dummy Variable 1/0
X28	6 p.m. to 7 p.m.	Independent	Dummy Variable 1/0
X29	7 p.m. to 8 p.m.	Independent	Dummy Variable 1/0
X30	8 p.m. to 9 p.m.	Independent	Dummy Variable 1/0
X31	9 p.m. to 10 p.m.	Independent	Dummy Variable 1/0
X32	10 p.m. to 11 p.m.	Independent	Dummy Variable 1/0
X33	11 p.m. to midnight	Independent	Dummy Variable 1/0
X34	Unused	-	-
X35	Unused	-	-
X36	Required Acceleration	Independent	Real Number
X37	Required Deceleration	Independent	Real Number
X38	Time to Stop Bar	Independent	Real Number

X39	15 Min Traffic on 17th St	Independent	Integer
X40	Presence of a Pedestrian Waiting to Cross 17th St	Independent	Dummy Variable 1/0
X41	Lane	Independent	Integer
X42	Presence of Pedestrian Countdown Timer	Independent	Dummy Variable 1/0
L1	Lane 1 (if X41 is significant)	Independent	Dummy Variable 1/0
L2	Lane 2 (if X41 is significant)	Independent	Dummy Variable 1/0
L3	Lane 3 (if X41 is significant)	Independent	Dummy Variable 1/0

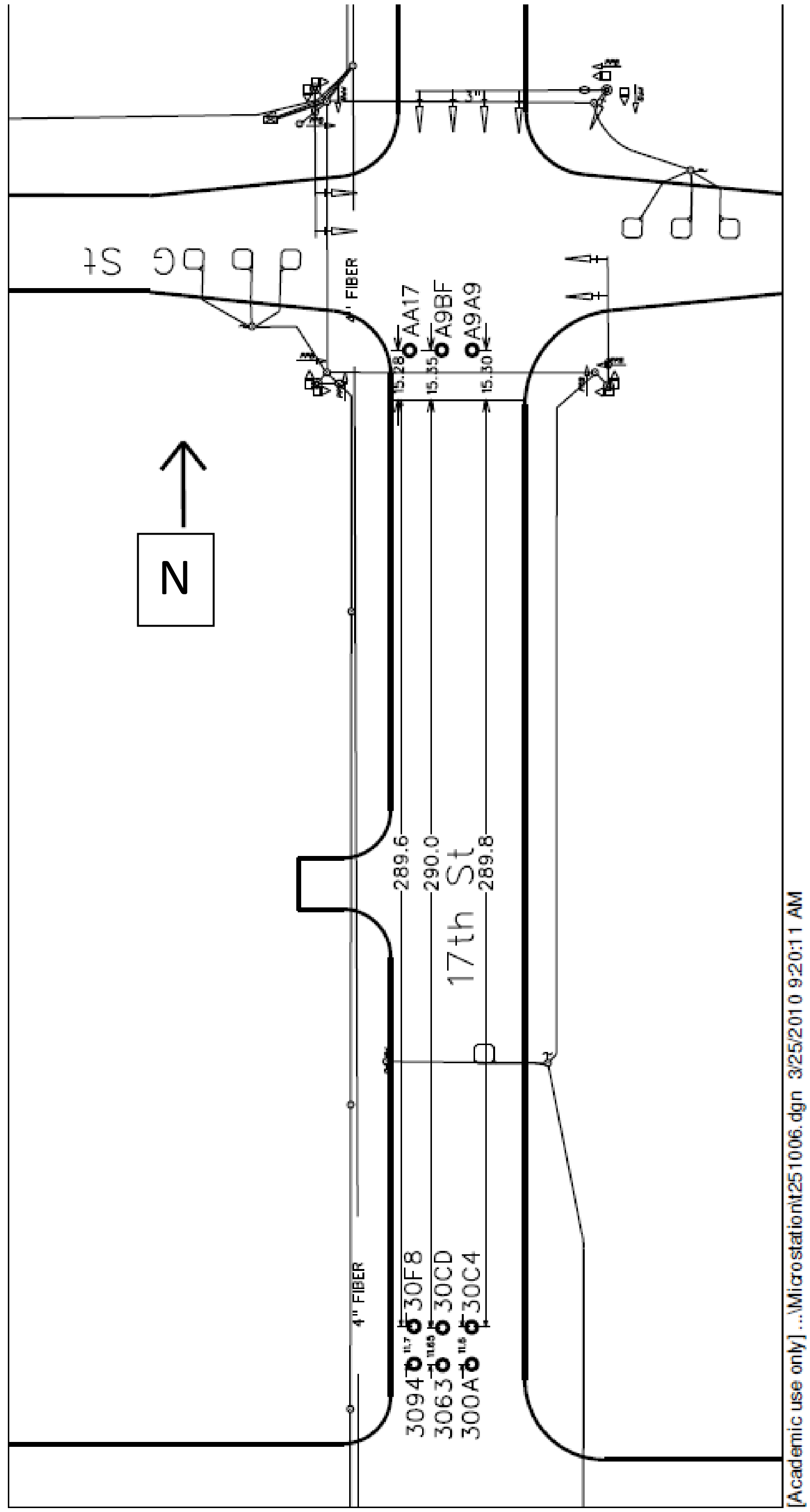
Variables Used in Speed at Stop Bar of Vehicles during the Yellow Phase Model

Variable	Description	Type	Coding
X1	Speed at Stop Bar	Dependent	Real Number
X2	Maximum Daily Outside Temperature (°F)	Independent	Integer
X3	Sunday	Independent	Dummy Variable 1/0
X4	Monday	Independent	Dummy Variable 1/0
X5	Tuesday	Independent	Dummy Variable 1/0
X6	Wednesday	Independent	Dummy Variable 1/0
X7	Thursday	Independent	Dummy Variable 1/0
X8	Friday	Independent	Dummy Variable 1/0
X9	Saturday	Independent	Dummy Variable 1/0
X10	Midnight to 1 a.m.	Independent	Dummy Variable 1/0
X11	1 a.m. to 2 a.m.	Independent	Dummy Variable 1/0
X12	2 a.m. to 3 a.m.	Independent	Dummy Variable 1/0
X13	3 a.m. to 4 a.m.	Independent	Dummy Variable 1/0
X14	4 a.m. to 5 a.m.	Independent	Dummy Variable 1/0
X15	5 a.m. to 6 a.m.	Independent	Dummy Variable 1/0
X16	6 a.m. to 7 a.m.	Independent	Dummy Variable 1/0
X17	7 a.m. to 8 a.m.	Independent	Dummy Variable 1/0
X18	8 a.m. to 9 a.m.	Independent	Dummy Variable 1/0
X19	9 a.m. to 10 a.m.	Independent	Dummy Variable 1/0
X20	10 a.m. to 11 a.m.	Independent	Dummy Variable 1/0
X21	11 a.m. to noon	Independent	Dummy Variable 1/0
X22	Noon to 1 p.m.	Independent	Dummy Variable 1/0
X23	1 p.m. to 2 p.m.	Independent	Dummy Variable 1/0
X24	2 p.m. to 3 p.m.	Independent	Dummy Variable 1/0
X25	3 p.m. to 4 p.m.	Independent	Dummy Variable 1/0
X26	4 p.m. to 5 p.m.	Independent	Dummy Variable 1/0

X27	5 p.m. to 6 p.m.	Independent	Dummy Variable 1/0
X28	6 p.m. to 7 p.m.	Independent	Dummy Variable 1/0
X29	7 p.m. to 8 p.m.	Independent	Dummy Variable 1/0
X30	8 p.m. to 9 p.m.	Independent	Dummy Variable 1/0
X31	9 p.m. to 10 p.m.	Independent	Dummy Variable 1/0
X32	10 p.m. to 11 p.m.	Independent	Dummy Variable 1/0
X33	11 p.m. to midnight	Independent	Dummy Variable 1/0
X34	Unused	-	-
X35	Speed at Onset of Yellow	Independent	Real Number
X36	Required Acceleration	Independent	Real Number
X37	Required Deceleration	Independent	Real Number
X38	Time to Stop Bar	Independent	Real Number
X39	15 Min Traffic on 17th St	Independent	Integer
X40	Presence of a Pedestrian Waiting to Cross 17th St	Independent	Dummy Variable 1/0
X41	Red Light Runner	Independent	Dummy Variable 1/0
X42	Lane	Independent	Integer
X43	Presence of Pedestrian Countdown Timer	Independent	Dummy Variable 1/0
L1	Lane 1 (if X42 is significant)	Independent	Dummy Variable 1/0
L2	Lane 2 (if X42 is significant)	Independent	Dummy Variable 1/0
L3	Lane 3 (if X42 is significant)	Independent	Dummy Variable 1/0

Appendix B – Locations of Sensys Sensors

S 17th St & G St:



G St
4" FIBER
AA17
A9BF
A9A9
15.28
15.35
15.30
N
289.6
290.0
17th St
289.8
30F8
30CD
30C4
3094
3063
300A
[Academic use only] ...\Microstation\t251006.dgn 3/25/2010 9:20:11 AM

N 27th St & Cornhusker Hwy: