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<b>16. Abstract</b> <p>Traffic signals are used to control the right of way at intersections. Strict engineering guidelines are published in the Manual on Uniform Traffic Control Devices (MUTCD) that engineers use to determine if a traffic signal is "warranted". The warrants provide consistent national balance between mobility, safety, efficiency, and costs. However, signalized intersections are often viewed by the general public as safer than unsignalized intersections. This belief is often heightened when there are personal injuries and even higher when children are involved. Parents, city officials, and local interest groups often vigorously request the installation of a traffic signal. After these requests are received, an engineering study is performed, and a traffic signal is often determined to be not warranted. It is the traffic engineer's responsibility to explain to the public why a signal is not needed. These results are not the desired response and in turn the public becomes more diligent for their cause and the cycle continues. This cycle of request and denial for a traffic signal is often seen at intersections adjacent to schools.</p> <p>This report examines signal installations at minimally warranted intersections between 1991 through 1999. Before and after accident data was analyzed at each of these intersections showing a difference in annualized crash rates for accident type and severity. This data suggests that for intersections not meeting warrants defined by the Manual on Uniform Traffic Control Devices, traffic signals should not be installed.</p>					
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FINAL REPORT  
FHWA/INDOT/JTRP-2002/32

**Traffic Signals in School Zones**

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## IMPLEMENTATION REPORT

The data summarized in Table 5-16 and Table 5-26 do not indicate it is beneficial to install traffic signals in school zones when the warrants defined by the Manual on Traffic Control Devices have not been met. In fact, they suggest that for intersections not meeting the warrants, traffic signals should not be installed. Based upon these findings, it is recommended that the Indiana Department of Transportation continue following nationally prescribed warrants for determining when a traffic signal should be installed.

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## CHAPTER 1. INTRODUCTION

Traffic signals are used to control the right of way at intersections. Strict engineering guidelines are published in the Manual on Uniform Traffic Control Devices (MUTCD) that engineers use to determine if a traffic signal is “warranted”. These guidelines are based upon years of national committee debates. Current warrants for traffic control devices trace their roots to other committee procedures developed for uniform signs, striping, and control devices [MUTCD 48]. The warrants provide consistent national balance between mobility, safety, efficiency, and costs.

However, signalized intersections are often viewed by the general public as safer than unsignalized intersections. This notion is often heightened when there are personal injuries and even higher when children are involved. Parents, city officials, and local interest groups often vigorously request the installation of a traffic signal.

After these requests are received, an engineering study is performed, and a traffic signal is often determined to be not warranted. It is the traffic engineer’s responsibility to explain that decision. These results are not the desired response and in turn the public become more diligent for their cause and the cycle continues. This cycle of request and denial for a traffic signal is often seen at intersections adjacent to schools. Table 1-1 shows an example of historical requests for warrant studies at the intersection at Kankakee Valley High School in Wheatfield, Indiana.

Table 1-1: Historical requests for signalization at Kankakee Valley High School in Wheatfield, Indiana.

Date	Action
March 19, 1992	Request for traffic control at intersection
April 2, 1992	Traffic count performed, Flashing Beacon warranted, Approved and Installed
January 29, 1993	Letter written by citizen expressing safety concerns at intersection
February 8, 1993	Request for reevaluation of traffic study from State Senator Wolf
February 15, 1993	INDOT confirms previous studies, notes prior advise to school to install Speed Limit sign with flashing beacon at own expense
May 13, 1994	Student injured in an accident
May 17, 1994	Request for signal installation
May 24, 1994	Traffic study performed
June 7, 1994	Results show no signal warranted
June 9, 1994	Recommendation for installation of Advance School Flasher
July 7, 1994	Request of signal installation by Senator Wolf
July 20, 1994	Request denied by INDOT
September 23, 1994	Senator Wolf forwards petitions of parents and teachers for reevaluation of traffic study
October 5, 1994	Denial of request, INDOT states signal cannot be installed without meeting warrants
October 25, 1995	Request for traffic study for signal installation
November 1, 1995	Turn lane suggested, improve right turn lane and sight distance
November 28, 1995	Traffic study performed
December 28, 1995	Results show no signal warranted
January 12, 1996	Data confirmed
March 11, 1996	School requests 'Cross Traffic Does Not Stop' sign
April 3, 1996	Signs deemed not appropriate
April 24, 1996	Signs denied, INDOT suggests reevaluation of the internal traffic flow
June 24, 1998	Introduction of project renovations (center lane installation)
August 15, 1998	Legal Notice of Improvements issued
October 1, 1998	School express concerns for intersection improvements
October 7, 1998	INDOT responds that Turn Lane will decrease conflicts and the widening will increase sight distance
October 13, 1998	Senator Wolf expresses concerns on improvements
November 2, 1998	Traffic data and improvement plans are reaffirmed
November 25, 1998	Representative Smith requests information on signal installation
December 9, 1998	Traffic study performed
January 8, 1999	Traffic signal found to be not warranted
April 24, 2000	Displeasure with improvements expressed by school and request delay construction
October 7, 2000	Student injured in an accident
October 23, 2000	Strong opinions expressed in local newspaper
October 25, 2000	Continued opinions in newspaper

School zones often, and understandably, generate spirited public and political involvement due to the strong emotions involved with the safety of the students. Traffic on roadways adjacent to schools is a focus for many safety issues. Traffic issues include high speed traffic, either from rural highways or vehicles not traveling at the posted speed limits, traffic congestion, minor street delays, and insufficient pedestrian precautions. Many of these conditions can increase the likelihood of crashes, especially with higher traffic volumes and speeds. In school zones, high traffic volumes are mainly seen during the morning and afternoon peak hours and last only for a short period of time. Much of this traffic comes from school buses, parents, staff, and students. Concerns for the dangers of severe crashes lead to public to seek solutions that may provide more safety. The perceived solution by the public to this problem is often the installation of a traffic signal.

#### 1.1. Project scope

There is a need for a quantitative before and after evaluation of crashes at signals that were installed where the warrants were justified by only a slim margin. This information may be used to determine if Indiana Department of Transportation (INDOT) should consider re-evaluating the procedure used to justify or deny a traffic signal. It is also noted that the 2000 National Manual on Uniform Traffic Control Devices (MUTCD) uses a traffic signal warrant that is met as only a first step in deciding a need to install a new traffic signal.

There is also a need for a development of short video clips documenting other factors affecting safety adjacent to a school, so that INDOT can effectively communicate these issues to the general public.

The national standards for justifying the installation are guidelines that work very well when signals are clearly justified or clearly not justified. It is not clear how well they work for borderline cases. Depending upon what the before/after data shows, the before/after information will either: be used to recommend that INDOT consider re-evaluating the procedures used to deny a traffic signal when criteria are almost met or be used to by INDOT to justify to the public why a signal request was denied.

With regards to the video clips, areas adjacent to schools often have undesirable circulation patterns and unstructured pedestrian movements that may be the cause of a safety problem. The Texas Department of Transportation (TxDOT) has developed a program called "Precious Cargo" that defines a procedure for school districts to work cooperatively with TxDOT to improve transportation features such as access and pedestrian movements. (TxDOT, 1999) The video clips will provide a mechanism for communicating to the schools, the importance of these alternative considerations.

## CHAPTER 2. BACKGROUND ON INDOT PROCEDURE FOR APPROVING SIGNALS

### 2.1. INDOT Procedure

The Indiana Department of Transportation follows the National Manual on Uniform Traffic Control Devices (MUTCD) procedure for approving traffic signals. This process begins with an engineering study of the traffic conditions, pedestrian characteristics, and physical characteristics of the location. (Section 4C.01, MUTCD 2000) This study includes a traffic count for a 12 hour period during an average day. Types of vehicles are classified during the peak hours during the count. Also part of the study is a pedestrian volume count during the same period. Information about surrounding facilities, approach speed limits, and intersection geometry are also noted and crash data from crashes during the previous year is collected.

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Table 2-1: Manual on Uniform Traffic Control Devices Traffic Signal Warrants.  
(Section 4C.01, MUTCD 2001)

Manual on Uniform Traffic Control Devices Traffic Signal Warrants	
Warrant 1:	Eight-Hour Vehicular Volume
Warrant 2:	Four-Hour Vehicular Volume
Warrant 3:	Peak Hour
Warrant 4:	Pedestrian Volume
Warrant 5:	School Crossing
Warrant 6:	Coordinated Signal System
Warrant 7:	Crash Experience
Warrant 8:	Roadway Network

---

From the engineering study, intersection conditions are evaluated using traffic signal warrants, shown in Table 2-1. The first step in determining if a signal should be installed is to determine if the conditions of the intersection meet the standards of any of the eight warrants and entails the use of engineering judgment during the analysis of the intersection. Often improvements to the

traffic flow can be made at the intersection without installing a traffic signal. This may include an addition of a turn lane, or improving sight distance.

For this study, five of the eight warrants are explained to further details. These include the 'Four-Hour Vehicular Volume', 'Peak Hour', 'Pedestrian Volume', 'School Crossing', and 'Crash Experience'. For each of the mentioned warrants, the standard procedure is explained and an example of this process is described. The intersection at Kankakee Valley High School in Wheatfield, Indiana is used as an example for the engineering analysis, shown in Figure 2-1. This intersection is two-way stop controlled with a flashing beacon.

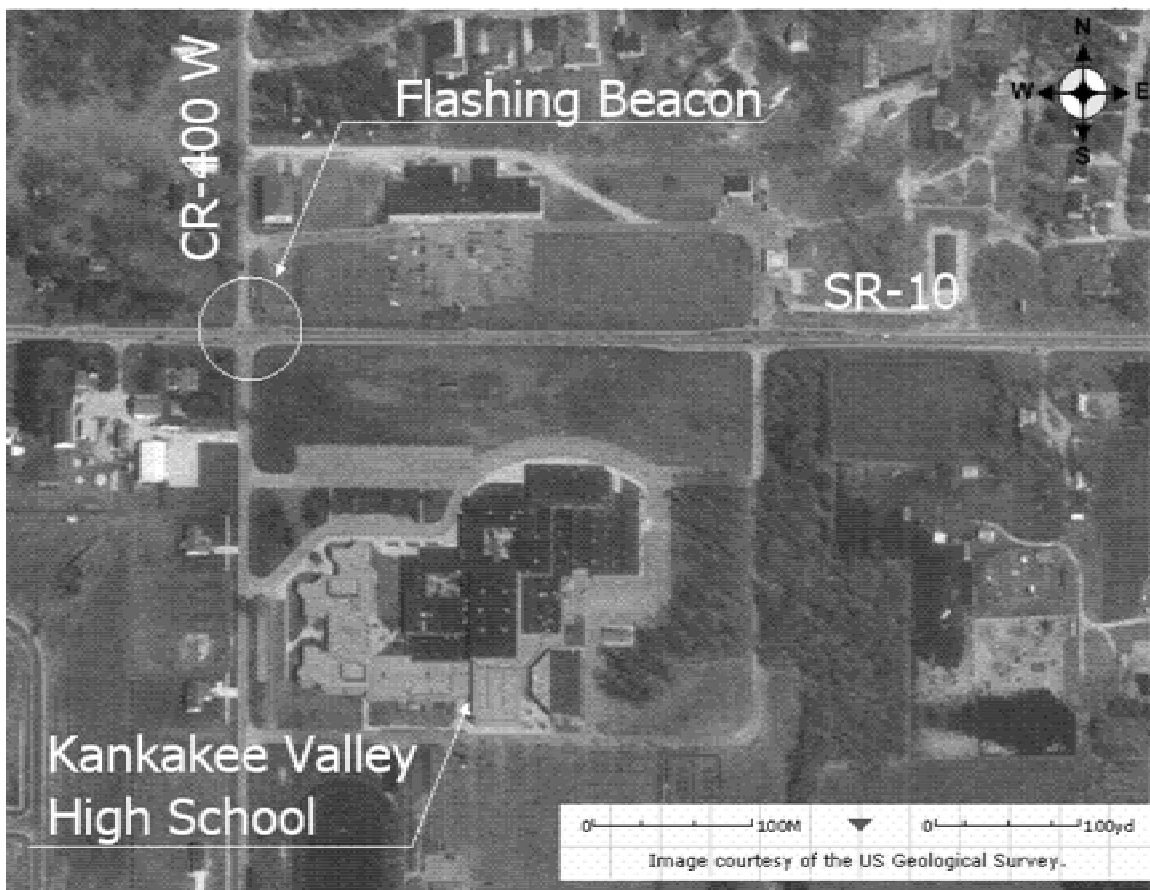


Figure 2-1: Aerial View of Kankakee Valley High School in Wheatfield, Indiana.

Traffic and pedestrian volumes were counted during peak hours during an average day. Only peak hour counts are performed as a result of previous traffic counts reported by INDOT. Results

of the vehicle and pedestrian volume counts are shown in Table 2-2. The major road, East and West bound, do not have high enough traffic volumes to be considered for an 'Eight-Hour Vehicular Volume' warrant. In such a case, other warrants are considered. Results of the engineering study and warrant analysis for this intersection are described in the following sections.

Table 2-2: Summary Table of Traffic Volumes at Kankakee Valley High School

	North Bound				East Bound				South Bound				West Bound			
	Pedestrian	Right Turn	Through	Left Turn	Pedestrian	Right Turn	Through	Left Turn	Pedestrian	Right Turn	Through	Left Turn	Pedestrian	Right Turn	Through	Left Turn
6:00-7:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:00-8:00	0	42	34	5	0	16	189	59	9	24	23	42	1	193	105	24
8:00-9:00	0	37	9	8	0	17	226	20	0	16	8	29	0	27	125	30
9:00-10:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:00-11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00-12:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12:00-1:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1:00-2:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2:00-3:00	0	36	20	7	1	9	172	24	0	10	21	24	1	42	182	53
3:00-4:00	0	49	29	8	0	22	260	26	0	41	34	97	40	68	195	66
4:00-5:00	0	55	39	7	0	14	169	29	0	27	34	41	0	55	198	65
5:00-6:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

## 2.2. Four-Hour Vehicular Volume

The Four-Hour Vehicular Volume warrant is based on the need of a traffic signal due to the volume of the cross traffic. A signal is warranted if "each of any four hour [traffic volumes] of an average day" (MUTCD, 2000) falls above the corresponding curves in Figure 2-2. As total volumes on the major street increase, the threshold volume on the minor street decrease.

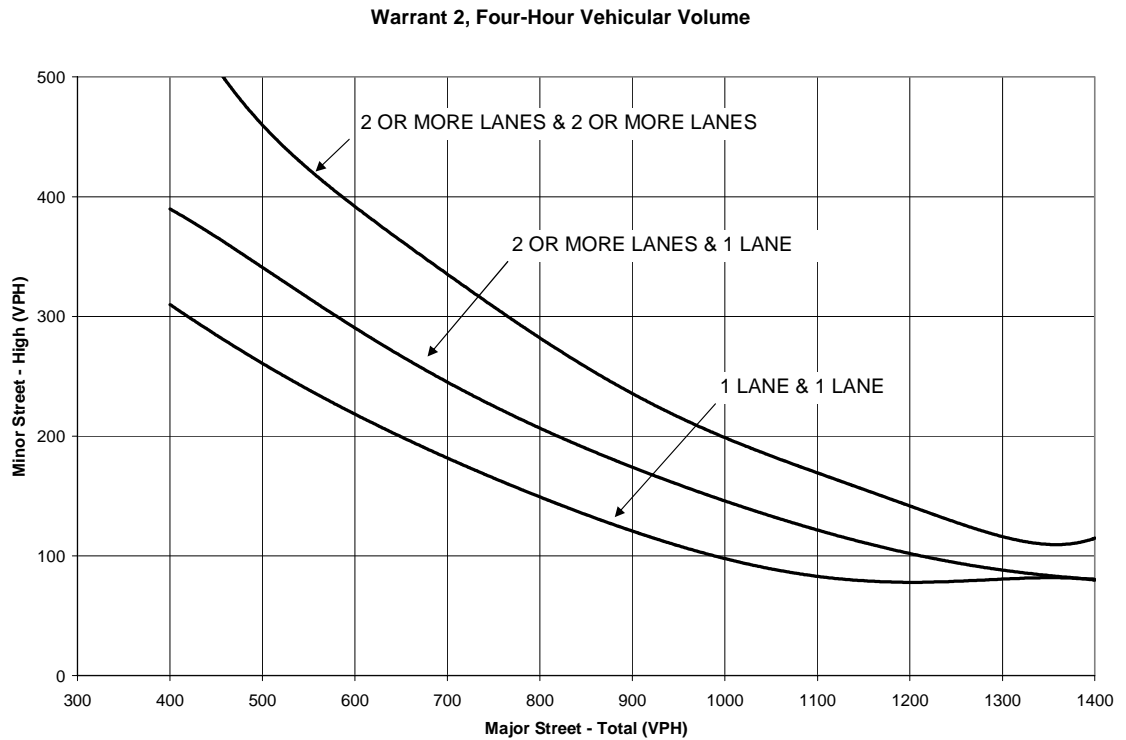


Figure 2-2: Warrant 2, Four-Hour Vehicular Volume Warrant.

For the intersection at Kankakee Valley High School, the collected peak hour data is plotted on Figure 2-2. Vehicular counts show that the maximum volume during the period is 672 vehicles on the major road and 172 vehicles on the minor road. This point is close to the lower limits of the '1 Lane & 1 Lane' threshold, but is still below the necessary volume. The other counted hours are below this point as seen in Figure 2-3. Results show that for this warrant, the intersection is not warranted for a traffic signal.

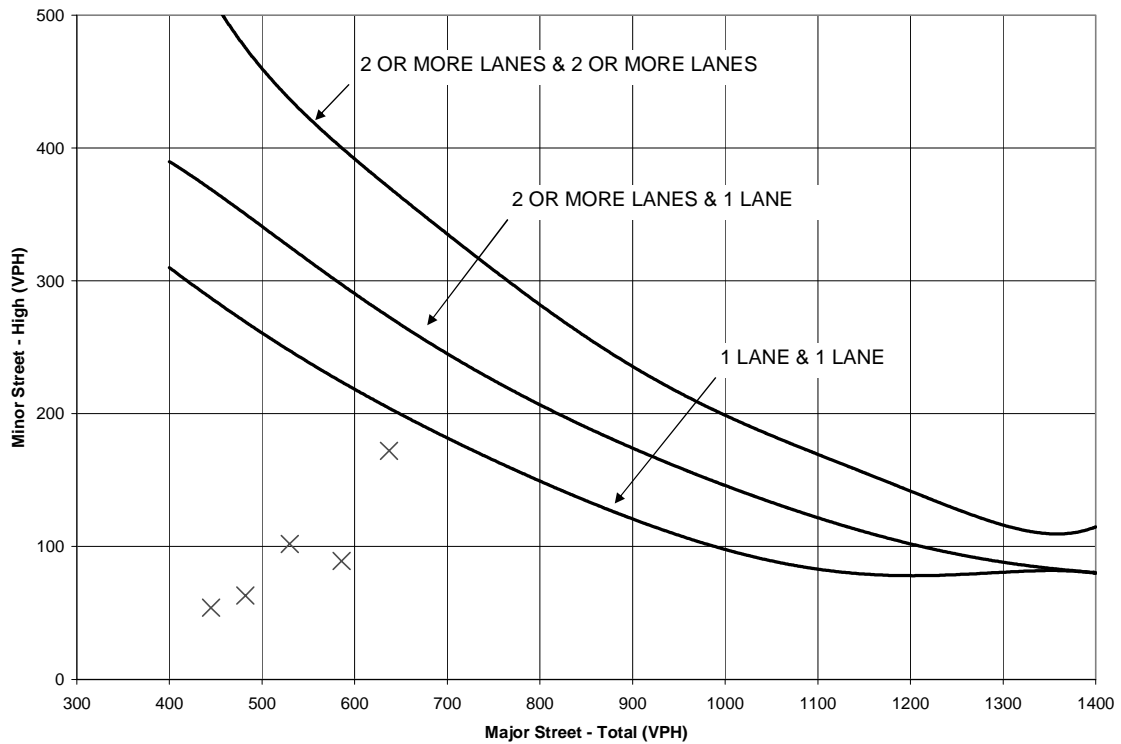


Figure 2-3: Four Hour Vehicular Volume Warrant Analysis for Intersection at Kankakee Valley High School.

### 2.3. Peak Hour

The Peak Hour warrant is used for an intersection where traffic volumes are high during a short period of time. This warrant is used at intersections with factories, commercial centers, or industrial parks. These locations often see a large influx of traffic volumes during peak hours. A traffic signal is considered when either of two criteria is met. The first criterion consists of several conditions where each of them is met. These conditions include the excess of four vehicle-hours time delay for a one-lane approach on the minor street<sup>1</sup>, more than 100 vehicles per hour for the same approach, and the total intersection volume equals or exceeds 800 vehicles per hour with

<sup>1</sup> This can be done with the Highway Capacity Manual unsignalized intersection procedure. However, it is rarely the controlling condition.

four approaches. The second criterion consists of plotting corresponding vehicular volumes on a graph, Figure 2-4, similar to the 'Four Hour Vehicular Volume' warrant. Any four consecutive 15-minute periods on an average day can be used. A traffic signal is considered when one hour falls above the curve.

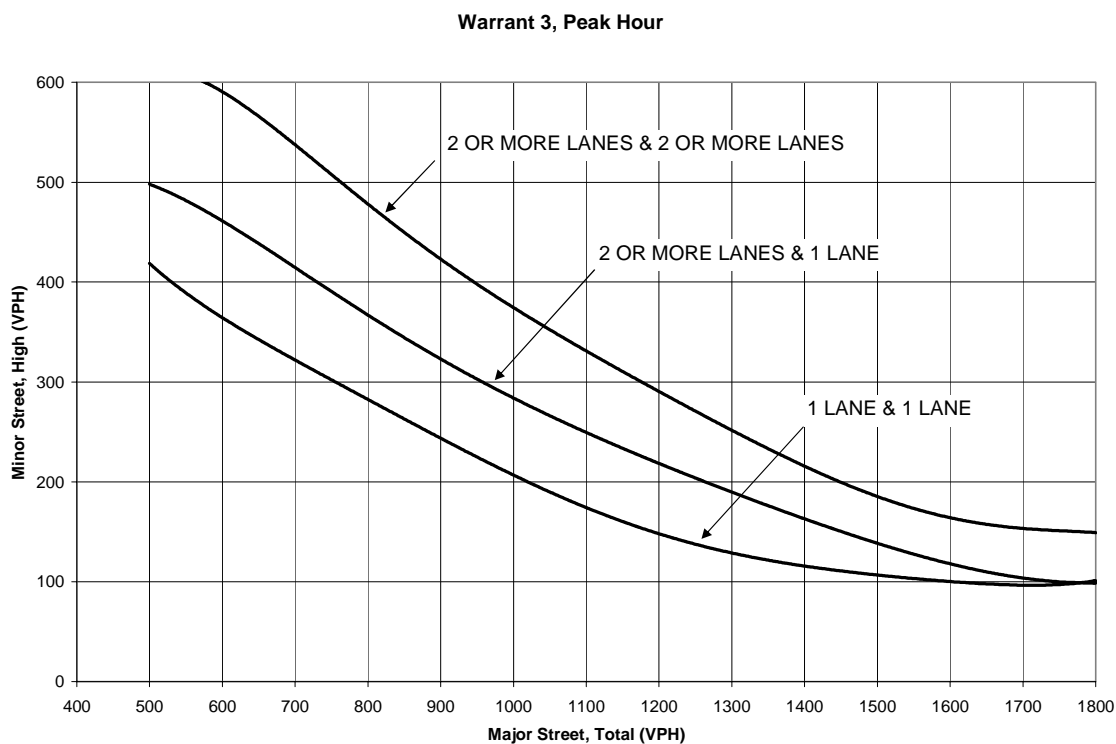


Figure 2-4: Warrant 3, Peak Hour Warrant.

Results from the traffic count in Figure 2-5 show that no four 15 minute periods meet the necessary requirements for consideration of a traffic signal installation. The highest volume period is 638 vehicles on the major road and 176 vehicles on the minor. The intersection volume is at the highest between the time of 3:00 pm and 4:30 pm. This is the time when the high school is dismissed from class. The exiting volume consists of mainly personal vehicles and a few school buses.

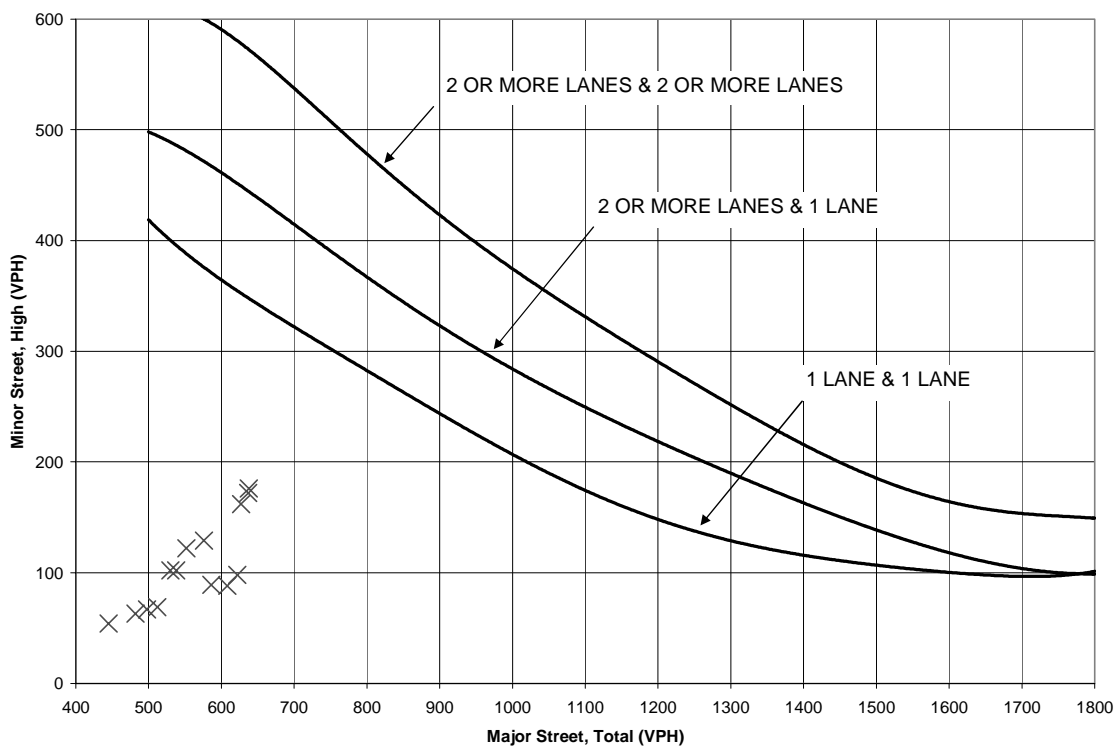


Figure 2-5: Peak Hour Warrant Analysis for Intersection at Kankakee Valley High School.

#### 2.4. Pedestrian Volume

The Pedestrian Volume warrant is used for intersections that have high volumes of pedestrian traffic. The warrant is satisfied when the pedestrian volume crossing the major street exceeds 100 pedestrians for each of four hours during an average day and there are less “than 60 gaps per hour in the traffic stream.” (Section 4C-10, MUTCD 2000) Both of these criteria must be met for any consideration for signal installation. Gaps are defined as the walking distance divided by the walking speed. The walking distance incorporates the distance from curb to curb or if there is a median, then from curb to median. This warrant is also limited to locations where there is not another traffic control device within 300 feet.

Along with a vehicular traffic count, pedestrians are counted. Observations of the intersection show that there are no crosswalks or a crossing guard at the intersection. Pedestrian counts

include any person that crosses the street within 1000 feet of the intersection. Results of the count are shown in Table 2-3. There are a total of 52 pedestrians counted during the peak hours of the day. This does not meet the first requirement of the 'Pedestrian Volume' warrant.

Table 2-3: Pedestrian Count at Kankakee Valley High School.

	North Bound	East Bound	South Bound	West Bound
6:00-7:00	0	0	0	0
7:00-8:00	0	0	9	1
8:00-9:00	0	0	0	0
9:00-10:00	0	0	0	0
10:00-11:00	0	0	0	0
11:00-12:00	0	0	0	0
12:00-1:00	0	0	0	0
1:00-2:00	0	0	0	0
2:00-3:00	0	1	0	1
3:00-4:00	0	0	0	40
4:00-5:00	0	0	0	0
5:00-6:00	0	0	0	0
Total	0	1	9	42

## 2.5. School Crossing

The School Crossing warrant is based on the need for a signal installation where there are children crossing a major street. Prior to the consideration of a signal installation, other means of traffic control are to be used such as warning signs, school speed zones, or crossing guards. After all other options are considered, a signal is warranted if the number of gaps in the traffic flow during a period is less than the number of minutes during the same period when the children are using the crossing.

This warrant is not applicable at Kankakee Valley High School since there are no other means of traffic control installed at the intersection. A flashing beacon was installed in 1992, but other means of traffic control were not installed. INDOT recommends installation of an 'Advance School Flasher' as seen in Figure 2-6 at the school's expense, but the school declined the recommendation. Other safety measures are recommended but not installed at the intersection. This refusal to consider other safety measures does not justify the application of the 'School Crossing' warrant to be applicable to this intersection.



Figure 2-6: Example of 'Advanced School Flasher'

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## 2.6. Crash Experience

The Crash Experience warrant is used when a signal is considered based on the frequency and severity of crashes. The signal installation is considered when each of the following criteria are met; if other methods do not reduce the frequency of crashes, five or more crashes during a 12-month period, and for each of any eight hours during an average day, the volume meets 80% of the 'Eight-Hour Volume' warrant requirements or the volume of the 'Pedestrian Volume'.

Of these two criteria, the volume requirements at Kankakee Valley High School were not met for this warrant. A total of 52 pedestrians were counted during the traffic analysis period, which is less than the required 100 pedestrians. Also, the traffic volumes do not meet the 80% columns of the 'Eight Hour Vehicular Volume' warrant. Failure to meet this criterion does not allow consideration for traffic signal installation.

## 2.7. Conclusions

This chapter examined different warrants and their procedure used in the consideration of traffic signal installation at lower volume intersections. Traffic counts are not the only source of information for traffic engineers. Intersection geometry, previous crash records, pedestrian movements, and safety precautions need to be examined before any decision is made.

The engineering study and analysis at Kankakee Valley High School describes an example of the many options and considerations needed during the warrant analysis process. Through the analysis, it is noted that a traffic signal installation is not warranted and is not recommended. According to the MUTCD, other safety measures should be considered before a traffic signal is installed. (MUTCD 2000)

## CHAPTER 3. LITERATURE REVIEW

This chapter discusses previous research on traffic signal warrant analysis, and minimally warranted signals. The chapter also includes a discussion on actions other agencies have taken on school zone safety. This will include the current and future plans for school zone safety developed by the City of Phoenix, Arizona. Finally, the chapter concludes with a summary of previous research findings.

### 3.1. Minimally Warranted Signals

Minimally warranted signals are typically located at intersections with high peak hour volumes and low off peak hour volumes. This is often encountered at factory entrances/exits, sporting facilities, and school entrances/exits. Problems are usually evident when vehicles are exiting the facility. Long delays and queues are created as high volume of traffic attempt to enter a major roadway system. Delays and queues increase if the major road contains high volumes. High volumes have low number of gaps and a higher chance for conflicts. Conflicts are defined as possible collisions or near misses as well as actual crashes. Delays and conflicts are sources for public concern and complaints to the local traffic engineer. Also frequency of crashes and/or severe crashes fuels the public interest for signal installation. Requests for signals are given to the traffic engineer and an engineering study is performed.

Engineering studies are performed at intersections to decide whether or not it fulfills any warrants for signal installation. After the analysis, if the signal is only minimally warranted or not at all, the engineer must use engineering judgment to decide if the signal should be installed. This decision incorporates information on the efficiency of intersection operation and safety. Overall delay and the potential increase of certain types of crashes are also considered. (Williams and Ardekani, 1996) After these factors are evaluated, the engineer decides the need of installing the signal.

It has been shown through simulation and research that signalization at minimally warranted signals will not improve intersection efficiency. (Williams and Ardekani, 1996) The effects of

signalization at minimally warranted intersections are discussed in previous research by Williams and Ardekani. Their research involves delay and crash data to determine the impacts of traffic signals at minimally warranted intersections.

Williams and Ardekani examined the impacts on efficiency and safety of minimally warranted signals. Efficiency is determined through simulation using field traffic data from a given list of intersections. Twelve different traffic patterns are classified and simulation of these patterns is performed. The traffic patterns are simulated through two-way stop control, all-way stop control, and actuated signalization. Safety is determined from previous crash data at the given intersections. Crash rates for a five-year period are used to determine the frequency of crashes. The intersections are then categorized by speed limit and city population size. The crashes are also separated by type of crashes and severity.

Results from the William and Ardekani study show that at low-speed urban situations, the number of crashes by severity is significantly higher for a signalized intersection compared to an unsignalized intersection. The research further states that similar to urban situations, there is an increase in crash rates in rural low-speed intersections and signalization can decrease the number of crashes. Also, it is found that 'Right Angle' crashes significantly decreased with signalization. Along with the decrease of 'Right Angle' crashes, there is an increase in 'Rear End' crashes.

The results of a decrease in 'Right Angle' crashes and an increase of 'Rear End' crashes are supported by King and Goldblatt. Their study examines intersection crashes at different intersections nationwide. Results show that there is a decrease of 45 percent for 'Right Angle' crashes. The study also discusses the increase of 'Total' crashes of eight percent and an 84 percent increase of 'Rear End' crashes at intersections in Michigan. Intersections in Concord, California "showed a reduction in total crashes" and 'Right Angle' crashes with an increase in 'Rear End' crashes after signal installation. (King and Goldblatt) King and Goldblatt also examine the affects of signalization at an unwarranted intersection. Results show that there is an increase of crash total, volume crash rate and crash disutility. Volume crash rate is defined by the total amount of crashes divided by peak-hour volume divided by 100. Crash disutility is defined as an "index of net economic loss" due to an adjustment of traffic flow patterns.

Through various studies, it can be generalized that there is a decrease in 'Right Angle' crash types and an increase in 'Rear End' and 'Left Turn' crashes after signal installation. Signalization

at an unwarranted intersection is found to decrease efficiency and increase delay and number of stops.

### 3.2. School Zone Safety

School zones are often a focus of safety concerns since there is an involvement of children. Safety issues in school zones include vehicular travel speeds, student pedestrian movements, and the interaction between the two issues. The following section discusses school zone traffic control devices and the resulting perception of the control devices by motorists. Along with the discussion on traffic control devices, a safety program developed by the City of Phoenix is presented.

#### 3.2.1. Motorist's Behavior

There are many studies that analyze the travel speeds through school zones. School zone speed limits can range from 15 miles per hour (mph) to 45 mph. Results show that there is a wide range of driver compliance to posted speed limits and travel speeds through school zones. Some studies show that driver compliance can be as low as 20 percent and some 85<sup>th</sup> percentile speed are more than 20 mph above the posted speed limit. (McCoy and Heimann, 1990) McCoy and Heimann also report that school zone speed limits are not effective in reducing speeds. It is also found that drivers are more likely to comply with a 25 mph speed limit or higher.

In another study, Saibel's "Vehicle Speeds in School Zones", close to half of the vehicles travel under 25 mph in a 20 mph zone. More than 25 percent travel higher than 30 mph and close to 9 percent travel more than 35 mph. There is a division in compliance where drivers either follow the posted speed limit or travel much faster. The drivers traveling at the higher speeds pose a risk to other vehicles as well as students walking to and from school. In Saibel's study, four different types of speed limit signs were used to compare driver reaction and travel speeds. The tested signs vary with the type of visibility and time indications. Of the tested signs, the flashing light school zone sign is found to be most effective in lowering the average speed. The flashing light sign gives motorist a visual indication of the school zone and an awareness of a speed change.

These results are also seen in Rosenbaum's "Speed Control in Rural School Zones". In this study, different sign conditions were used to compare the effectiveness of speed control. Sign conditions vary in signage. The most effective conditions were found to be signs with flashing lights warning of a reduction in speed and upcoming school zone. These conditions were found to decrease travel speed from an average of 55 mph to 35 mph. The other sign conditions without flashing lights reduce the average speed to 40 mph. It is concluded that the more information that the motorist visualizes; the more likely the motorist will change their behavior.

### 3.2.2. Effectiveness of Traffic Control Devices

The previous research indicates that visual aids lead to driver's awareness and a reduction in speed. This is a direct result from the use of flashing light signs. Aggarwal and Mortensen examine the effectiveness of flashing light signs in "Do Advance School Flashers Reduce Speed". This study discusses the placement and operation of the flashers. Results from the study show that there was a significant reduction in average travel speeds through the tested school zones.

Another study suggests the effectiveness of advance school flashers in Schrader's "Study of Effectiveness of Selected School Zone Traffic Control Devices". In this study, five different traffic control devices were tested to see any reduction in travel speeds. The five devices are post-mounted flashing beacons, lavender transverse stripes, span wire-mounted flashing beacons, fiber-optic signs, and painted pavement markings. The use of mounted flashing beacons and fiber optic signs results in a reduction in 85<sup>th</sup> percentile speeds. Lavender stripes reduce the speeds only for a short period. The span wire-mounted flashing beacon does show immediate reduction, but does have reduction in speeds at the end of the study. Speeds are also reduced with the use of pavement markings. The use of traffic control devices are found to be effective when it is visible to motorists. Drivers are more aware of the speed limit and school zones when there are flashing beacons. (Reiss and Robertson, 1976)

### 3.2.3. School Safety Plans

Part of increasing school zone safety is the development of a safety plan that can involve all aspects of a school corporation. The following section examines the safety plan of the City of Phoenix in Arizona. The plan is a set of recommendations that would improve safety at schools as listed in Table 3-1. These recommendations can apply to any school and incorporates the help from the city, law enforcement, the school and parents. The shared responsibilities for each of the recommendations show the need of each group to work together. Some recommendations are not applicable to all schools and many are site dependent.

Table 3-1: Responsibilities of Phoenix, Arizona Recommendations Summary Table.

<b>Recommendations</b>	<b>City of Phoenix</b>	<b>Law Enforcement</b>	<b>School</b>	<b>Parent</b>
Two adult crossing guards at wide streets			X	
Stronger speed enforcement at schools	X	X		
Paint SCHOOL pavement stencil on high-speed approaches	X			
Larger student waiting areas	X			
Student "Stand Back" lines	X			
"Safest Route to School" Plans	X		X	X
Red-Light cameras at signals	X		X	
Zero tolerance at 15 mph zones, 5 mph tolerance elsewhere	X	X		
Brighter vests, and other uniform pieces			X	
International pedestrian signals	X			
More safety training of students	X		X	X
Crossing guard training			X	
Prevent future elementary schools on major streets	X		X	
Arterial streets as attendance boundaries			X	
Arterial streets as bussing boundaries	X		X	
Buffers and/or wider sidewalks	X		X	
Consider raising fines or adding points for school zone citations	X	X		

### 3.2.3.1. Pedestrian Consideration

A main focus in the safety plan is the involvement and consideration of pedestrians. Most of the recommendations deal with the increase safety of pedestrians. Increasing pedestrian safety can always start with an organized route to and from the school. This is seen in a “Safest Route to School” program seen in Figure 3-1.

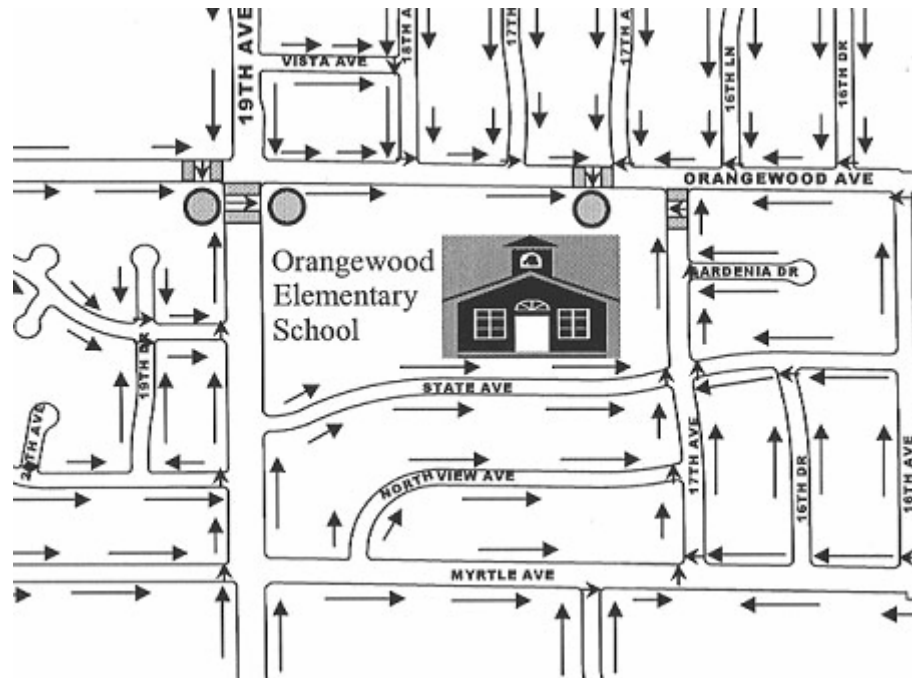


Figure 3-1: Example of a “Safest Route to School” plan. (Grote 2002)

In addition to making a consistent route for the students, the city must accommodate pedestrians on these streets. This includes the development of sidewalks, pedestrian signals, and waiting areas. City engineers and planners need to make it possible for pedestrians to walk beside the streets. Facilities need to be built to allow these pedestrian movements. The recommendations of larger waiting areas, Figure 3-2 and stand back areas, Figure 3-3 allow students and other pedestrians to stay away from moving traffic while waiting to cross the street. Without these additional areas, children are exposed to traffic and may overflow into the street, Figure 3-3a.



Figure 3-2: Larger waiting areas at intersections. (Grote 2002)

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a) Before



b) After

Figure 3-3: Before and After installation of "Stand Back" lines. (Grote 2002)

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Along with creating the facilities for pedestrians, there is a need for adjustments in operations. There are two parts in the adjustment of operations. The first is the signalization at intersections. Universal pedestrian signals, Figure 3-4, and appropriate pedestrian walk times are needed to allow pedestrians to cross the street. Pedestrian walk times need to be adjusted for the pedestrian walking speed. The standard walk times may not be sufficient time for children to walk

across the intersection. In addition to increasing pedestrian walk and clearance times, pedestrian recall can be utilized to increase safety. Pedestrian recall allows for the 'Pedestrian Walk' indication to be called during each cycle. The second adjustment in operations is the use of crossing guards. Crossing guards help with students crossing the street. Motorists become aware that children are present and as previously discussed, travel speeds decrease. At larger intersections, two crossing guards can be beneficial as seen in Figure 3-5. Crossing guards need to be visible. The use of brighter and more reflective clothes will help in the motorist's recognition of crossing guards.

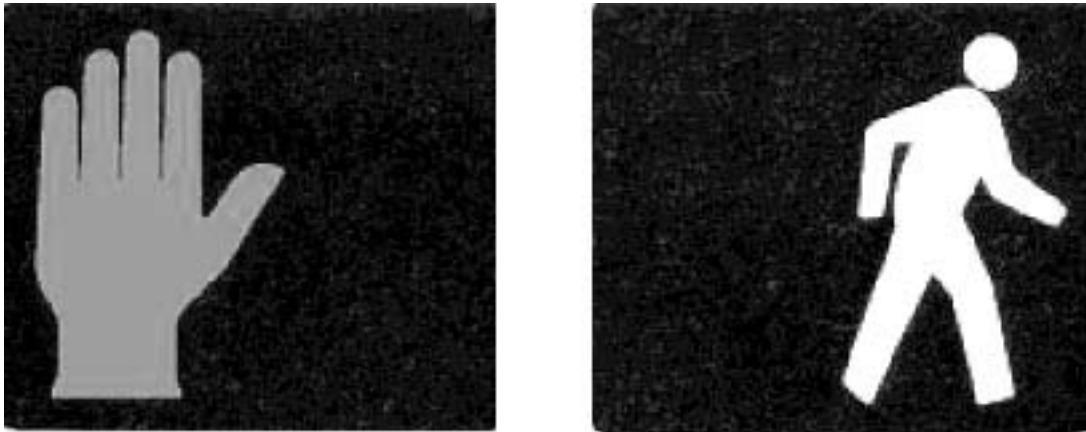


Figure 3-4: Universal pedestrian signals. (Grote 2002)

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Figure 3-5: Two crossing guards at wider streets. (Grote 2002)

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#### 3.2.3.2. Law Enforcement

The following section discusses the use of law enforcement in the increase of safety in school zones. In the previous section, the average travel speed through a school is typically higher than the posted speed limit. An effective method of speed control is having a strong police presence in the school zone as seen in Figure 3-6. Motorists often decrease their speeds to or below the speed limit when there is police present. Another way of deterring high speeds through school zones is the use of increased school zone violation fines as shown in Figure 3-7. A zero-tolerance policy can be incorporated along with school zone violation fines. All of these recommendations depend on the cooperation of the city and law enforcement.



Figure 3-6: Speed Enforcement in School Zones. (Grote 2002)

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<b><i>Existing</i></b> <b><u>School Zone Violation Fines</u></b>	
For speeding or passing in a School Zone	
ARS 28-797	Fine: \$110 Points: 2

Figure 3-7: Example of School Zone Violation Fines. (Grote 2002)

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### 3.2.3.3. Education

Educating everyone involved in school zone safety is a necessary step and process. This begins with the students, shown in Figure 3-8. Parents and teacher begin the learning process by teaching the students basics in safety. Safety training allows students to be aware of the dangers with vehicles and intersections. This process continues to law enforcement officers and city administrators. The people who implement and enforce the safety plan need to understand the goals and mission of the program.



Figure 3-8: Education and training of students. (Grote 2002)

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### 3.2.4. Application to Indiana School Zones

The City of Phoenix developed these recommendations to help improve the safety of their local school districts. From the recommendations, the State of Indiana can use these ideas and apply them to the numerous school districts within the state. Indiana school districts can be divided into two categories, city and county. Each of the recommendations will have different impacts to the different districts and application can be adjusted accordingly as noted in Table 3-2.

Table 3-2: Recommendations for Indiana City and County School Districts.

<b>Recommendations</b>	<b>Indiana City School Districts</b>	<b>Indiana County School Districts</b>
Two adult crossing guards at wide streets	X	
Stronger speed enforcement at schools	X	X
Paint SCHOOL pavement stencil on high-speed approaches	X	X
Larger student waiting areas	X	
Student "Stand Back" lines	X	
"Safest Route to School" Plans	X	
Red-Light cameras at signals	X	
Zero tolerance at 15 mph zones, 5 mph tolerance elsewhere	X	X
Brighter vests, and other uniform pieces	X	X
International pedestrian signals	X	
More safety training of students	X	X
Crossing guard training	X	X
Prevent future elementary schools on major streets	X	X
Arterial streets as attendance boundaries	X	
Arterial streets as bussing boundaries		
Buffers and/or wider sidewalks	X	
Consider raising fines or adding points for school zone citations	X	X

Indiana city school districts will be able to use recommendations related to pedestrians due to the higher percentage of students within a walking distance to the schools. The improvements for

pedestrians will promote a safer walk to school for the students. If students are willing to walk to school, there will be less vehicular traffic going to and from the school. The use of arterial streets as attendance boundaries can help by preventing students from crossing heavy traffic streets and to stay on local streets.

A common problem that both city and county school districts have is traffic speed control. Traffic speeds are often higher than the posted speed limit and is a danger to the students and other vehicles. Law enforcement and traffic control recommendations are used to try to regulate and lower speeds through school zones. Speeds can be lowered through two methods, driver awareness and enforcement. Signs and stencil markings along the road can increase driver awareness and help with lowering travel speeds and increasing caution near schools. Enforcement around school zones can also help with lowering speeds. Drivers will be aware of the police presence around schools and abide by the speeds limits and other traffic laws.

Another precaution that can be done for city and county school districts is to prevent future schools to be built on major streets. Placing a school near a major road can lead to problems with traffic and safety. During the planning stages, the location of the school can help with increasing safety.

The last applicable recommendation is the safety education and training of students. Making the students aware of the possible dangers around the school and their trip to and from school can help prevent crashes.

## CHAPTER 4. METHODOLOGY

One of the primary objectives of this research was to conduct a before and after study of crashes at signals that are minimally warranted.

The following data analysis is a process that is comprised of two parts. The first part consists of categorizing and totaling all of the crashes at the identified intersection by crash type and severity. The crashes are also separated by when they occurred, before or after the signal is installed. The second part is an analysis of the before after crash data for each intersection to determine if there are any “statistically significant” changes in safety for different types and severity of crashes. The following section describes the data collection and first part of the analysis process.

### 4.1. Data Collection

In consultation with INDOT, several signals installed during the last seven years where warrants were barely satisfied were identified. Crash data for up to three-five years prior and three-five years after were obtained. From the previous list of intersections, intersections that are adjacent to school zones are identified. Along with the previous list of intersections, groups of intersection adjacent to schools are identified.

Due to limitations of available crash data, the list of intersections was narrowed to nineteen intersections. These intersections had signals installed between the years of 1992 and 1997. The corresponding crash data for these intersections were obtained and is dated from 1991 to 1999. There is a varying amount of crash data for the intersections since the signals at each intersection were installed at different years. This variation ranges between one to five years for each of the before and after cases. The construction year is not included in the total of crashes. This eliminates any crashes due to the variation of circumstances and changing conditions at the intersection. Table 4-1 lists the intersections with the corresponding installation year as well as

the number of crashes before and after the traffic signal installation. A total of 63 years of before and 72 years of after data are collected along with 146 crashes and 310 crashes respectively.

Table 4-1: Collected Data Summary Table.

Intersection	Installation Year	Years Before	Accidents Before	Years After	Accidents After
1	1997	5	2	2	1
2	1997	5	0	2	7
3	1997	5	21	2	7
4	1992	1	3	5	20
5	1992	1	11	5	54
6	1992	1	9	5	33
7	1992	1	3	5	10
8	1994	3	9	5	28
9	1995	4	28	4	29
10	1997	5	0	2	7
11	1996	5	1	3	0
12	1996	5	10	3	8
13	1992	1	0	5	9
14	1994	3	3	5	25
15	1995	4	28	4	33
16	1994	3	0	5	1
17	1997	5	7	2	12
18	1992	1	5	5	24
19	1996	5	6	3	2
Total		63	146	72	310

#### 4.2. Crash Categorization

The collected crash data was then categorized into crash types and severity of crashes. The types of crashes, explained in Appendix A, are separated into ten groups listed as follows:

- 'Rear End, Neither Turning'
- 'Head On, Neither Turning'
- 'Same Direction Sideswipe'
- 'Opposite Direction Sideswipe'

- 'Off Road Collision'
- 'Right Angle'
- 'Left and Right Turns'
- 'Left Turn'
- 'Right Turn'
- 'Other/Unknown'

Each crash is also separated by severity;

- 'Property Damage'
- 'Personal Injury'
- 'Fatal'

For each intersection, an aggregate total of each type and severity of crashes was calculated for the before and after years. Along with the crash types and severities, the total crash counts for before and after signal installation are used during analysis.

#### 4.3. Crash Data Sensitivity

The study areas for this project were 0-200 feet, 0-500 feet and 0-1000 feet from the intersection. An example of the study areas are seen in Figure 4-1. The study area of 200 feet includes crashes only within 200 feet of the intersection. This area follows INDOT standards for intersection crash studies. The study area of 500 feet allows for the inclusion of crashes from extended queued traffic at intersections and includes crashes within 500 feet from the intersection. Crashes within the study area of 1000 feet allows for the inclusion of any secondary entrances, which are typically seen in school zones.

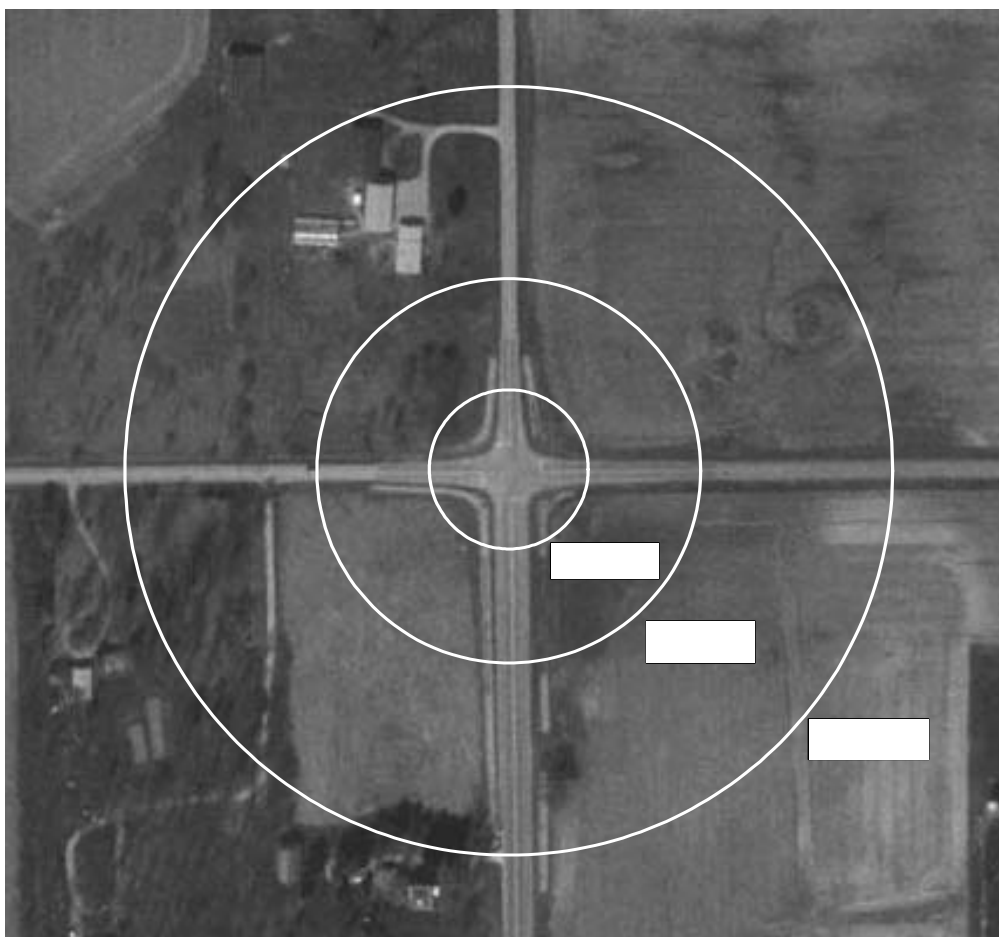


Figure 4-1: Illustration of 200, 500 1000 feet data collection radius.

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#### 4.4. Crash Data Summary

The following tables show crash data summarized for each intersection by type and severity. These summaries are also separated by distances from the intersection. Along with the summarized data tables, two fatalities are denoted in each of the crash type tables. The fatality is depicted as shaded spaces in the tables.

#### 4.4.1. Fatal Crashes

There were two fatalities in the data set. The fatality at Intersection 18 is a 'Right Angle' crash. This crash occurred before the signal installation period on Monday, August 26, 1991 at 5:01 pm. Details of this crash show that the victim of this crash was an under aged unlicensed person driving a moped. The victim enters the intersection without seeing an oncoming vehicle. The oncoming vehicle strikes the moped and the victim is thrown from the moped onto the pavement. The victim later dies at the hospital the following day.

The second fatality occurs at Intersection 19 with a 'Left Turn' crash type. This fatality occurred on Saturday, July 16, 1994 at 2:17 pm. This crash consists of a driver failing to yield to the right of way. The driver turns left without watching for oncoming vehicles. The person's view is also obstructed by another vehicle turning left in the opposite direction. The oncoming vehicle, driven by the victim, strikes the turning vehicle causing it to deflect towards the right and hit a stopped vehicle on the minor road.

#### 4.4.2. Study Area Summaries

Table 4-2 shows the details of crash types for each intersection within 200 feet. There are a total of 128 crashes before installation and 291 crashes after signal installation. These crashes are further categorized in Table 4-3 by severity.

Table 4-2: Summary Table of Crash Types Within 200 feet of the Intersection.

Intersection	Counts by Crash Types																									
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total			
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After		
1	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	6		
3	5	2	6	4	0	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	20	7		
4	1	5	0	11	0	0	0	0	0	1	0	0	3	5	0	0	0	0	0	0	0	3	3	20		
5	1	5	6	36	0	0	2	1	0	1	0	0	1	8	0	0	0	0	1	0	1	5	11	51		
6	1	5	4	22	0	1	0	0	0	0	0	1	5	3	0	0	0	1	0	0	0	4	9	32		
7	1	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	7	3	8		
8	3	5	6	19	0	0	0	2	0	0	0	0	1	2	0	0	0	3	1	0	1	2	9	28		
9	4	4	6	5	1	1	1	0	0	0	0	1	9	9	0	1	0	7	2	0	4	3	23	27		
10	5	2	0	3	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6		
11	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
12	5	3	1	2	0	0	0	0	0	0	0	0	2	3	0	0	1	1	0	0	0	0	4	6		
13	1	5	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	9		
14	3	5	1	7	0	0	1	2	0	0	0	1	0	5	0	0	1	8	0	0	0	2	3	25		
15	4	4	7	2	0	2	0	0	2	0	0	0	6	2	0	0	3	2	0	0	9	23	27	31		
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		
17	5	2	1	4	0	1	0	1	0	0	0	0	5	2	0	0	0	2	0	0	0	2	6	12		
18	1	5	0	8	0	0	0	1	0	0	0	0	2	5	0	0	1	3	0	0	0	4	3	21		
19	5	3	0	1	0	0	1	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	5	1		
Total	63	72	40	129	1	7	10	11	2	2	1	4	38	46	0	1	9	27	6	0	21	64	128	291		

 Indicates one fatality

Table 4-3: Summary Table for Severity of Crashes Within 200 feet of the intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	0	0	0	0
2	5	2	0	4	0	2	0	0
3	5	2	17	6	3	1	0	0
4	1	5	2	19	1	1	0	0
5	1	5	11	46	0	5	0	0
6	1	5	9	21	0	11	0	0
7	1	5	3	6	0	2	0	0
8	3	5	4	22	5	6	0	0
9	4	4	18	22	5	5	0	0
10	5	2	0	4	0	2	0	0
11	5	3	0	0	1	0	0	0
12	5	3	2	4	2	2	0	0
13	1	5	0	6	0	3	0	0
14	3	5	2	16	1	9	0	0
15	4	4	18	21	9	10	0	0
16	3	5	0	1	0	0	0	0
17	5	2	2	9	4	3	0	0
18	1	5	2	16	0	5	1	0
19	5	3	3	1	1	0	1	0
<b>Total</b>	<b>63</b>	<b>72</b>	<b>94</b>	<b>224</b>	<b>32</b>	<b>67</b>	<b>2</b>	<b>0</b>

When the study area is expanded to 500 feet, there is an increase in the total data set as seen in Table 4-4 and Table 4-5. There are 11 more crashes before the traffic signal installation and seven more after signal installation.

Table 4-4: Summary Table for Crash Types Within 500 feet of the Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7				
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
4	1	5	0	11	0	0	0	0	0	1	0	0	3	5	0	0	0	0	0	0	0	3	3	20				
5	1	5	6	37	0	0	2	1	0	1	0	0	1	9	0	0	0	0	1	0	1	5	11	53				
6	1	5	4	22	0	1	0	1	0	0	0	1	5	3	0	0	0	1	0	0	0	4	9	33				
7	1	5	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	2	7	3	10				
8	3	5	6	19	0	0	0	2	0	0	0	0	1	2	0	0	0	3	1	0	1	2	9	28				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7			
11	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0				
12	5	3	3	2	0	0	0	0	0	0	0	0	2	3	0	0	1	2	0	0	0	0	6	7				
13	1	5	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	9				
14	3	5	1	7	0	0	1	2	0	0	0	1	0	5	0	0	1	8	0	0	0	2	3	25				
15	4	4	7	3	0	2	0	0	2	0	0	0	6	2	0	0	3	2	0	0	9	23	27	32				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1				
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
18	1	5	0	8	0	0	0	2	0	0	0	0	2	5	0	0	1	3	0	0	0	4	3	22				
19	5	3	0	1	0	0	1	0	0	0	0	0	3	0	0	0	1	0	1	0	0	0	6	1				
Total	63	72	46	133	2	7	10	14	3	2	1	5	39	49	0	1	10	28	7	0	21	65	139	304				

 Indicates one fatality

Table 4-5: Summary Table for Severity of Crashes Within 500 feet of the intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
4	1	5	2	19	1	1	0	0
5	1	5	11	47	0	6	0	0
6	1	5	9	22	0	11	0	0
7	1	5	3	7	0	3	0	0
8	3	5	4	22	5	6	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
11	5	3	0	0	1	0	0	0
12	5	3	3	4	3	3	0	0
13	1	5	0	6	0	3	0	0
14	3	5	2	16	1	9	0	0
15	4	4	18	21	9	11	0	0
16	3	5	0	0	0	0	0	0
17	5	2	3	9	4	3	0	0
18	1	5	2	17	0	5	1	0
19	5	3	4	1	1	0	1	0
<b>Total</b>	<b>63</b>	<b>72</b>	<b>98</b>	<b>230</b>	<b>39</b>	<b>73</b>	<b>2</b>	<b>0</b>

Table 4-6 summarizes the crash types for crashes within 1000 feet of the intersection and shows additional crashes with the larger study area. There is an increase of seven before crashes and six after crashes.

Table 4-6: Summary Table for Crash Types Within 1000 feet of the Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7				
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
4	1	5	0	11	0	0	0	0	0	1	0	0	3	5	0	0	0	0	0	0	0	3	3	20				
5	1	5	6	38	0	0	2	1	0	1	0	0	1	9	0	0	0	0	1	0	1	5	11	54				
6	1	5	4	22	0	1	0	1	0	0	0	1	5	3	0	0	0	1	0	0	0	4	9	33				
7	1	5	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	2	7	3	10				
8	3	5	6	19	0	0	0	2	0	0	0	0	1	2	0	0	0	3	1	0	1	2	9	28				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7			
11	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0				
12	5	3	6	2	0	0	0	0	0	0	0	0	3	4	0	0	1	2	0	0	0	0	10	8				
13	1	5	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	9				
14	3	5	1	7	0	0	1	2	0	0	0	1	0	5	0	0	1	8	0	0	0	2	3	25				
15	4	4	8	4	0	2	0	0	2	0	0	0	6	2	0	0	3	2	0	0	9	23	28	33				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1				
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
18	1	5	1	8	1	0	0	3	0	0	0	0	2	5	0	0	1	3	0	0	0	5	5	24				
19	5	3	0	1	0	0	1	0	0	0	0	0	3	1	0	0	1	0	1	0	0	0	6	2				
Total	63	72	51	135	3	7	10	15	3	2	1	5	40	51	0	1	10	28	7	0	21	66	146	310				

 Indicates one fatality

Table 4-7: Summary Table for Severity of Crashes Within 1000 feet of the intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
4	1	5	2	19	1	1	0	0
5	1	5	11	48	0	6	0	0
6	1	5	9	22	0	11	0	0
7	1	5	3	7	0	3	0	0
8	3	5	4	22	5	6	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
11	5	3	0	0	1	0	0	0
12	5	3	7	4	3	4	0	0
13	1	5	0	6	0	3	0	0
14	3	5	2	16	1	9	0	0
15	4	4	19	22	9	11	0	0
16	3	5	1	0	0	0	0	0
17	5	2	3	9	4	3	0	0
18	1	5	3	19	1	5	1	0
19	5	3	4	2	1	0	1	0
<b>Total</b>	<b>63</b>	<b>72</b>	<b>105</b>	<b>235</b>	<b>40</b>	<b>74</b>	<b>2</b>	<b>0</b>

#### 4.5. School Zone Intersections

From the previous list of intersections, seven intersections are located in school zones. Schools are located at a corner of each of these intersections. For this set of intersections, there are 32 years of before and 19 years of after installation data with 58 and 64 crashes respectively. Crash data is categorized by crash type and severity of crash. From the data, there are no 'Fatal' crashes that are reported for any of the school zone intersections. All of the crashes consist of 'Property Damage' or 'Personal Injury' crash severities. The data is also separated by distances

from the intersection as seen in Table 4-8. Crashes are categorized by crash types and are limited to the crashes within 200 feet of the intersection. For this study area, there are a total of 50 crashes before and 59 crashes after signal installation. These crashes are then separated by severity as seen in Table 4-8.

Table 4-8: Summary Table for Crash Types Within 200 feet of the School Zone Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	6				
3	5	2	6	4	0	0	5	1	0	0	1	0	1	1	0	0	1	0	1	0	4	1	20	7				
9	4	4	6	5	1	1	1	0	0	0	0	1	9	9	0	1	0	7	2	0	4	3	23	27				
10	5	2	0	3	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1				
17	5	2	1	4	0	1	0	1	0	0	0	0	5	2	0	0	0	2	0	0	0	2	6	12				
<b>Total</b>	<b>32</b>	<b>19</b>	<b>14</b>	<b>18</b>	<b>1</b>	<b>4</b>	<b>6</b>	<b>5</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>1</b>	<b>15</b>	<b>13</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>9</b>	<b>3</b>	<b>0</b>	<b>8</b>	<b>8</b>	<b>50</b>	<b>59</b>				

Table 4-9: Summary Table for Severity of Crashes Within 200 feet of the School Zone Intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	0	0	0	0
2	5	2	0	4	0	2	0	0
3	5	2	17	6	3	1	0	0
9	4	4	18	22	5	5	0	0
10	5	2	0	4	0	2	0	0
16	3	5	0	1	0	0	0	0
17	5	2	2	9	4	3	0	0
<b>Total</b>	<b>32</b>	<b>19</b>	<b>38</b>	<b>46</b>	<b>12</b>	<b>13</b>	<b>0</b>	<b>0</b>

The following tables, Table 4-10 and Table 4-11, show results of crashes within 500 feet of school zone intersections. In this study area, there are 58 crashes before and 64 crashes after signal installation. This is an increase from the 200 feet study area.

Table 4-10: Summary Table for Crash Types Within 500 feet of the School Zone Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7				
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	7				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1				
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
<b>Total</b>	<b>32</b>	<b>19</b>	<b>18</b>	<b>20</b>	<b>2</b>	<b>4</b>	<b>6</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>16</b>	<b>14</b>	<b>0</b>	<b>1</b>	<b>3</b>	<b>9</b>	<b>3</b>	<b>0</b>	<b>8</b>	<b>9</b>	<b>58</b>	<b>64</b>				

Table 4-11: Summary Table for Severity of Crashes Within 500 feet of the School Zone Intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
16	3	5	0	0	0	0	0	0
17	5	2	3	9	4	3	0	0
<b>Total</b>	<b>32</b>	<b>19</b>	<b>40</b>	<b>48</b>	<b>18</b>	<b>15</b>	<b>0</b>	<b>0</b>

Table 4-12: Summary Table for Crash Types Within 1000 feet of the School Zone Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7				
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	7				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1				
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
<b>Total</b>	<b>32</b>	<b>19</b>	<b>18</b>	<b>20</b>	<b>2</b>	<b>4</b>	<b>6</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>16</b>	<b>14</b>	<b>0</b>	<b>1</b>	<b>3</b>	<b>9</b>	<b>3</b>	<b>0</b>	<b>8</b>	<b>9</b>	<b>58</b>	<b>64</b>				

Table 4-13: Summary Table for Severity of Crashes Within 1000 feet of the School Zone Intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
16	3	5	1	0	0	0	0	0
17	5	2	3	9	4	3	0	0
<b>Total</b>	<b>32</b>	<b>19</b>	<b>41</b>	<b>48</b>	<b>18</b>	<b>15</b>	<b>0</b>	<b>0</b>

The last study area includes crashes within 1000 feet of the intersection. From Table 4-12, the total amount of crashes does not change from 500 feet. There is also no change in crash severity as seen in Table 4-13.

## CHAPTER 5. STATISTICAL ANALYSIS

The following section describes statistical analysis of the data tabulated in Chapter 4. The statistical tests compares the before and after crash counts. Statistic tests are performed to determine if improvement or degradation in safety are statistically significant. The tests use a 10% significance level and the negative binomial distribution. This analysis is described through an example procedure using data from Intersection 8.

These tests are performed for each intersection at three different distances, 200, 500, and 1000 feet. The analysis procedure documented in this chapter is with data from 500 feet from the intersection. Results are then presented for 200 feet and 1000 feet distances.

### 5.1. Negative Binomial Distribution Test

The negative binomial distribution is used for the prediction of crashes at these intersections. This distribution is a generalization of the Poisson distribution. The Poisson distribution is not a correct assumption when randomness of crashes is higher than those caused by purely random chance. The negative binomial distribution allows for the higher dispersion of crash counts. The critical values for 10% significant level are determined using the negative binomial distribution. Observed crashes are then compared to these critical values to determine significant changes as a result of the treatment.

### 5.2. Summary of Data

Shown in Table 5-1 are the listings of each intersection with categorized crashes within 500 feet, which are separated by crashes before and after signal installation. There are a total of 63 before

years and 71 after years. These years are not equal due to limitations of data availability. Along with a categorization by crash types, each crash is also classified by severity in Table 5-2. Based on the collected data, each crash is a 'Property Damage', 'Personal Injury', or 'Fatal'.

Table 5-1: Summary Table of Crash Type Within 500 feet of the Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After		
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1			
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7			
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
4	1	5	0	11	0	0	0	0	0	1	0	0	3	5	0	0	0	0	0	0	0	3	3	20				
5	1	5	6	37	0	0	2	1	0	1	0	0	1	9	0	0	0	0	1	0	1	5	11	53				
6	1	5	4	22	0	1	0	1	0	0	0	1	5	3	0	0	0	1	0	0	0	4	9	33				
7	1	5	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	2	7	3	10				
8	3	5	6	19	0	0	0	2	0	0	0	0	1	2	0	0	0	3	1	0	1	2	9	28				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7			
11	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0			
12	5	3	3	2	0	0	0	0	0	0	0	0	2	3	0	0	1	2	0	0	0	0	0	6	7			
13	1	5	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	0	9				
14	3	5	1	7	0	0	1	2	0	0	0	1	0	5	0	0	1	8	0	0	0	2	3	25				
15	4	4	7	3	0	2	0	0	2	0	0	0	6	2	0	0	3	2	0	0	9	23	27	32				
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
18	1	5	0	8	0	0	0	2	0	0	0	0	2	5	0	0	1	3	0	0	0	4	3	22				
19	5	3	0	1	0	0	1	0	0	0	0	0	3	0	0	0	1	0	1	0	0	0	6	1				
<b>Total</b>	<b>63</b>	<b>72</b>	<b>46</b>	<b>133</b>	<b>2</b>	<b>7</b>	<b>10</b>	<b>14</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>5</b>	<b>39</b>	<b>49</b>	<b>0</b>	<b>1</b>	<b>10</b>	<b>28</b>	<b>7</b>	<b>0</b>	<b>21</b>	<b>65</b>	<b>139</b>	<b>304</b>				

Table 5-2: Summary Table of Severity of Crashes Within 500 feet of the Intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
4	1	5	2	19	1	1	0	0
5	1	5	11	47	0	6	0	0
6	1	5	9	22	0	11	0	0
7	1	5	3	7	0	3	0	0
8	3	5	4	22	5	6	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
11	5	3	0	0	1	0	0	0
12	5	3	3	4	3	3	0	0
13	1	5	0	6	0	3	0	0
14	3	5	2	16	1	9	0	0
15	4	4	18	21	9	11	0	0
16	3	5	0	0	0	0	0	0
17	5	2	3	9	4	3	0	0
18	1	5	2	17	0	5	1	0
19	5	3	4	1	1	0	1	0
Total	63	72	98	230	39	73	2	0

### 5.3. Predicted Number of Crashes

The following section describes the test procedure. Each intersection is represented with number of years, number of crashes, and Annual Average Daily Traffic (AADT) for the periods before and after the treatment. This data is obtained for each of the types and severity of crashes to calculate a predicted crash value if the treatment had not been installed. Variability of the mean estimate is also calculated. After each intersection is analyzed, an aggregate sum of crashes is

calculated. The differences between aggregate sums of occurred and predicted crashes are then tested by comparing the critical values and the reported actual crashes after signal installation.

Data for each intersection is adjusted for changes in the overall exposure to risk. Changes in the exposure to risk is the product of a ratio of number of years before and after signal installation ( $Y_A/Y_B$ ) and the ratio of AADT ( $AADT_A/AADT_B$ ) during the same time periods. AADTs for the midpoint years of before and after periods are used. For some of the intersections, AADT data is not available for the desired years. In such a case, growth rates are determined for these intersections and the desired year AADT is calculated. An exposure to risk factor of 1.0 relates to similar conditions before and after signal installation. Complete calculations of the exposure to risk factor ( $(Y_A/Y_B)*(AADT_A/AADT_B)$ ) are shown in Table 5-3.

Intersection 8 is used as an example to describe the analysis procedure. Three years of before crash data and five years of after crash data were collected for this intersection where a traffic signal was installed in 1994.

- The ratio of years is calculated by dividing the five after years by the three before years. The resulting ratio years of crash data ( $Y_A/Y_B$ ) is 1.67.
- For the ratio of AADT ( $AADT_A/AADT_B$ ), traffic data for the intersection was available for 1991 and 1996. The AADT during 1991 was 16,940 vehicles and for 1996, the volume was 16,560 vehicles. The ratio of traffic growth factor, ( $AADT_A/AADT_B$ ), is 0.98. Note for this case, the value is slightly less than 1.0 because of the decline in AADT.

These ratios are then multiplied calculating the overall adjustment for exposure to risk. The resulting adjustment for exposure to risk for Intersection 8 is 1.63. For clarity, this value is repeated in the second column of Table 5-4.

Table 5-3: Summary Table of Change in Exposure to Risk.

Intersection	Installation Year	Years			Annual Average Daily Traffic								Adjusted AADT Rate, $AADT_A/AADT_B$	Combined Exposure To Risk, E, Year and AADT, $(E_A/E_B)$
		Years Before, $Y_B$	Years After, $Y_A$	Adjusted Year Rate $Y_A/Y_B$	Year	AADT (vehicle/day)	Year	AADT (vehicle/day)	Growth rate	Before Year Midpoint	After Year Midpoint			
1	1997	5	2	0.40	1995	12560	1999	13190	1.012	1994	1998	1.05	0.42	
2	1997	5	2	0.40	1995	9490	1999	9030	0.988	1994	1998	0.95	0.38	
3	1997	5	2	0.40	1995	6930	2000	9110	1.056	1994	1998	1.24	0.50	
4	1992	1	5	5.00	1995	26040	2000	28380	1.017	1991	1995	1.07	5.36	
5	1992	1	5	5.00	1995	26040	2000	28380	1.017	1991	1995	1.07	5.36	
6	1992	1	5	5.00	1995	19860	2000	17530	0.975	1991	1995	0.90	4.52	
7	1992	1	5	5.00	1995	3970	1999	7410	1.169	1991	1995	1.87	9.33	
8	1994	3	5	1.67	1991	16940	1996	16560	0.995	1992	1997	0.98	1.63	
9	1995	4	4	1.00	1995	8720	1999	9930	1.033	1992	1997	1.18	1.18	
10	1997	5	2	0.40	1990	14010	1996	19420	1.056	1994	1998	1.24	0.50	
11	1996	5	3	0.60	1993	23800	1998	28030	1.033	1993	1998	1.18	0.71	
12	1996	5	3	0.60	1990	13200	1996	14880	1.020	1993	1998	1.10	0.66	
13	1992	1	5	5.00	1995	6130	1999	5920	0.991	1991	1995	0.97	4.83	
14	1994	3	5	1.67	1991	18050	1997	22030	1.034	1992	1997	1.18	1.97	
15	1995	4	4	1.00	1993	9970	1998	11150	1.023	1992	1997	1.12	1.12	
16	1994	3	5	1.67	1992	24420	1996	27820	1.033	1992	1997	1.18	1.96	
17	1997	5	2	0.40	1993	38090	1998	40620	1.013	1994	1998	1.05	0.42	
18	1992	1	5	5.00	1995	18690	1999	14990	0.946	1991	1995	0.80	4.01	
19	1996	5	3	0.60	1995	16630	1999	14810	0.971	1993	1998	0.87	0.52	

The combined exposure to risk factors change is multiplied with the actual number of crashes before installation to calculate the predicted value of crashes if the traffic signal is not installed. This procedure is performed for each of the intersections for type and severity of crashes. Aggregate sums of each type and severity are calculated for the predicted value of crashes and the actual values of before and after crashes as shown in the following tables.

Table 5-4: Summary Calculations for 'Rear End, Neither Turning', 'Head On, Neither Turning', and 'Same Direction Sideswipe' at a Distance of 500 feet.

Intersection	Combined Exposure To Risk, E, Year and AADT, ( $E_A/E_B$ )	Rear End, Neither Turning			Head On, Neither Turning			Same Direction Sideswipe		
		Accidents Before	Accidents After	Predicted After, $a_{0A}$	Accidents Before	Accidents After	Predicted After, $a_{0A}$	Accidents Before	Accidents After	Predicted After, $a_{0A}$
1	0.42	2	1	0.84	0	0	0.00	0	0	0.00
2	0.38	0	2	0.00	0	2	0.00	0	0	0.00
3	0.50	6	4	2.99	1	0	0.50	5	1	2.49
4	5.36	0	11	0.00	0	0	0.00	0	0	0.00
5	5.36	6	37	32.14	0	0	0.00	2	1	10.71
6	4.52	4	22	18.10	0	1	0.00	0	1	0.00
7	9.33	0	1	0.00	0	0	0.00	0	1	0.00
8	1.63	6	19	9.78	0	0	0.00	0	2	0.00
9	1.18	9	6	10.59	1	1	1.18	1	0	1.18
10	0.50	0	3	0.00	0	0	0.00	0	2	0.00
11	0.71	1	0	0.71	0	0	0.00	0	0	0.00
12	0.66	3	2	1.99	0	0	0.00	0	0	0.00
13	4.83	0	2	0.00	0	0	0.00	0	0	0.00
14	1.97	1	7	1.97	0	0	0.00	1	2	1.97
15	1.12	7	3	7.83	0	2	0.00	0	0	0.00
16	1.96	0	0	0.00	0	0	0.00	0	1	0.00
17	0.42	1	4	0.42	0	1	0.00	0	1	0.00
18	4.01	0	8	0.00	0	0	0.00	0	2	0.00
19	0.52	0	1	0.00	0	0	0.00	1	0	0.52
Total		46	133	87.34	2	7	1.67	10	14	16.87

For each crash type in Table 5-4, the observed before crashes are multiplied by the exposure to risk factor,  $E_A/E_B$ , (Table 5-3) to calculate a predicted after crash value. For example, at Intersection 8, the adjustment factor 1.63 is multiplied by the number of 'Rear End, Neither Turning' crash type (6). A predicted crash value ( $a_{0A}$ ) of 9.78 is calculated. This value is then added together with the other predicted values for the other 18 intersections to calculate an aggregate sum of predicted after crash values of 87.34.

Table 5-5: Summary Calculations for 'Opposite Direction Sideswipe', 'Off Road Collision', and 'Right Angle' at a Distance of 500 feet.

Intersection	Combined Exposure To Risk, E, Year and AADT, (E <sub>A</sub> /E <sub>B</sub> )	Opposite Direction Sideswipe			Off Road Collision			Right Angle		
		Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>
1	0.42	0	0	0.00	0	0	0.00	0	0	0.00
2	0.38	0	0	0.00	0	0	0.00	0	0	0.00
3	0.50	0	0	0.00	1	0	0.50	1	1	0.50
4	5.36	0	1	0.00	0	0	0.00	3	5	16.07
5	5.36	0	1	0.00	0	0	0.00	1	9	5.36
6	4.52	0	0	0.00	0	1	0.00	5	3	22.62
7	9.33	0	0	0.00	0	0	0.00	0	1	0.00
8	1.63	0	0	0.00	0	0	0.00	1	2	1.63
9	1.18	0	0	0.00	0	1	0.00	10	10	11.76
10	0.50	0	0	0.00	0	1	0.00	0	1	0.00
11	0.71	0	0	0.00	0	0	0.00	0	0	0.00
12	0.66	0	0	0.00	0	0	0.00	2	3	1.33
13	4.83	0	0	0.00	0	1	0.00	0	0	0.00
14	1.97	0	0	0.00	0	1	0.00	0	5	0.00
15	1.12	2	0	2.24	0	0	0.00	6	2	6.71
16	1.96	0	0	0.00	0	0	0.00	0	0	0.00
17	0.42	1	0	0.42	0	0	0.00	5	2	2.11
18	4.01	0	0	0.00	0	0	0.00	2	5	8.02
19	0.52	0	0	0.00	0	0	0.00	3	0	1.56
Total		3	2	2.66	1	5	0.50	39	49	77.66

Similar calculations are followed for 'Rear End, Neither Turning', 'Head On, Neither Turning', and 'Same Direction Sideswipe'. Table 5-5 shows the calculations for 'Opposite Direction Sideswipe', 'Off Road Collision', and 'Right Angle' at a distance of 500 feet from the intersection. Table 5-6 shows calculations of 'Left and Right Turns', 'Left Turn', and 'Right Turn' crashes within 500 feet from the intersection.

Table 5-6: Summary Calculations for 'Left and Right Turns', 'Left Turns', and 'Right Turn' at a Distance of 500 feet.

Intersection	Combined Exposure To Risk, E, Year and AADT, (E <sub>A</sub> /E <sub>B</sub> )	Left and Right Turns			Left Turn			Right Turn		
		Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>
1	0.42	0	0	0.00	0	0	0.00	0	0	0.00
2	0.38	0	0	0.00	0	0	0.00	0	0	0.00
3	0.50	0	0	0.00	2	0	1.00	1	0	0.50
4	5.36	0	0	0.00	0	0	0.00	0	0	0.00
5	5.36	0	0	0.00	0	0	0.00	1	0	5.36
6	4.52	0	0	0.00	0	1	0.00	0	0	0.00
7	9.33	0	0	0.00	0	0	0.00	1	0	9.33
8	1.63	0	0	0.00	0	3	0.00	1	0	1.63
9	1.18	0	1	0.00	1	7	1.18	2	0	2.35
10	0.50	0	0	0.00	0	0	0.00	0	0	0.00
11	0.71	0	0	0.00	0	0	0.00	0	0	0.00
12	0.66	0	0	0.00	1	2	0.66	0	0	0.00
13	4.83	0	0	0.00	0	0	0.00	0	0	0.00
14	1.97	0	0	0.00	1	8	1.97	0	0	0.00
15	1.12	0	0	0.00	3	2	3.36	0	0	0.00
16	1.96	0	0	0.00	0	0	0.00	0	0	0.00
17	0.42	0	0	0.00	0	2	0.00	0	0	0.00
18	4.01	0	0	0.00	1	3	4.01	0	0	0.00
19	0.52	0	0	0.00	1	0	0.52	1	0	0.52
Total		0	1	0.00	10	28	12.69	7	0	19.69

Table 5-7: Summary Calculations for 'Other / Unknown', and 'Total' at a Distance of 500 feet.

Intersection	Combined Exposure To Risk, E, Year and AADT, (E <sub>A</sub> /E <sub>B</sub> )	Other / Unknown			Total		
		Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>
1	0.42	0	0	0.00	2	1	0.84
2	0.38	0	3	0.00	0	7	0.00
3	0.50	4	1	1.99	21	7	10.45
4	5.36	0	3	0.00	3	20	16.07
5	5.36	1	5	5.36	11	53	58.92
6	4.52	0	4	0.00	9	33	40.72
7	9.33	2	7	18.66	3	10	28.00
8	1.63	1	2	1.63	9	28	14.66
9	1.18	4	3	4.71	28	29	32.94
10	0.50	0	0	0.00	0	7	0.00
11	0.71	0	0	0.00	1	0	0.71
12	0.66	0	0	0.00	6	7	3.98
13	4.83	0	6	0.00	0	9	0.00
14	1.97	0	2	0.00	3	25	5.90
15	1.12	9	23	10.07	27	32	30.20
16	1.96	0	0	0.00	0	1	0.00
17	0.42	0	2	0.00	7	12	2.95
18	4.01	0	4	0.00	3	22	12.03
19	0.52	0	0	0.00	6	1	3.11
Total		21	65	42.41	139	304	261.48

Table 5-7 shows the calculations of the crash type 'Other/Unknown' and 'Total'. The total values are the sum of each crash type for the before and after periods. At Intersection 8, there were nine crashes before signal installation and 28 after installation. The nine observed crashes are multiplied by the exposure to risk factor for a predicted value of 28.00.

Along with crash types, severity of crashes is also analyzed. The change in exposure to risk factor is also applied to the number of crash severities, shown in Table 5-8. Predicted values for 'Property Damage', 'Personal Injury', and 'Fatal' are calculated. For Intersection 8, the 1.63 exposure to risk factor is multiplied to the four observed 'Property Damage' crashes to calculate 6.52 predicted 'Property Damage' crashes and the five observed 'Personal Injury' crashes for an 8.15 predicted 'Personal Injury' crashes. These predicted values are then added together for an aggregate sum.

Table 5-8: Summary Calculations for 'Property Damage', 'Personal Injury', and 'Fatal' at a Distance of 500 feet.

Intersection	Combined Exposure To Risk, E, Year and AADT, (E <sub>A</sub> /E <sub>B</sub> )	Property Damage			Personal Injury			Fatal		
		Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>	Accidents Before	Accidents After	Predicted After, a <sub>0A</sub>
1	0.42	1	0	0.42	1	1	0.42	0	0	0.00
2	0.38	0	5	0.00	0	2	0.00	0	0	0.00
3	0.50	17	6	8.46	4	1	1.99	0	0	0.00
4	5.36	2	19	10.71	1	1	5.36	0	0	0.00
5	5.36	11	47	58.92	0	6	0.00	0	0	0.00
6	4.52	9	22	40.72	0	11	0.00	0	0	0.00
7	9.33	3	7	28.00	0	3	0.00	0	0	0.00
8	1.63	4	22	6.52	5	6	8.15	0	0	0.00
9	1.18	19	24	22.35	9	5	10.59	0	0	0.00
10	0.50	0	4	0.00	0	3	0.00	0	0	0.00
11	0.71	0	0	0.00	1	0	0.71	0	0	0.00
12	0.66	3	4	1.99	3	3	1.99	0	0	0.00
13	4.83	0	6	0.00	0	3	0.00	0	0	0.00
14	1.97	2	16	3.94	1	9	1.97	0	0	0.00
15	1.12	18	21	20.13	9	11	10.07	0	0	0.00
16	1.96	0	0	0.00	0	0	0.00	0	0	0.00
17	0.42	3	9	1.26	4	3	1.68	0	0	0.00
18	4.01	2	17	8.02	0	5	0.00	1	0	4.01
19	0.52	4	1	2.08	1	0	0.52	1	0	0.52
Total		98	230	213.52	39	73	43.43	2	0	4.53

#### 5.4. Negative Binomial Test

With the aggregate sums of number of crashes, actual and predicted, a negative binomial distribution test is performed. From the test, two critical values are determined for each of the following two tests at 10% significant levels. Two tests are used for each type and severity of crashes. For each test, the critical values are compared to the actual number of crashes after installation.

- Test 1 evaluates if there is a statistically significant reduction in crashes after the installation of a traffic signal. For this test, a decrease in crashes is significant if the observed number of crashes is less than the critical value.
- Test 2 evaluates if there is a statistically significant increase in observed crashes after the signal is installed. An increase in crashes is significant if the observed number of crashes is greater than the critical value.

### 5.5. Results

Test 1 and Test 2 are performed on each crash type, shown in Table 5-9, and severity of crashes, Table 5-10. For example, the category 'Rear End, Neither Turning' had 133 crashes, but only 87.34 were predicted. Based upon the negative binomial model, the critical value for determining if there was a statistically significant increase was 163 crashes. Consequently there was statistically significant evidence to support the hypothesis that there was an increase of crashes in this category after the signal installation. The results from Test 1 for crashes within 500 feet show that there is significant decrease of crashes for 'Right Angle', and 'Right Turn'. Results from Test 2 for the same data set show that there is significant increase of crashes for 'Rear End, Neither Turning', 'Head On, Neither Turning', 'Off Road Collision' 'Left Turn', 'Other/Unknown', and 'Personal Injury'. 'Left and Right Turns' did not have sufficient data to perform either test since there is only one reported crash of this type. Table 5-11 shows the summary of statistical calculations for the negative binomial test.

Table 5-9: Results Table for Crash Types Within 500 feet of All Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	133	87.34	63	NO	113	YES
Head On, Neither Turning	7	1.67	0	NO	4	YES
Same Direction Sideswipe	14	16.87	7	NO	29	NO
Opposite Direction Sideswipe	2	2.66	0	NO	6	NO
Off Road Collision	5	0.50	0	NO	2	YES
Right Angle	49	77.66	55	YES	102	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	28	12.69	5	NO	21	YES
Right Turn	0	19.69	7	YES	36	NO
Other / Unknown	65	42.41	23	NO	64	YES
Total	304	261.48	216	NO	308	NO

Table 5-10: Results Table for Severity of Crashes Within 500 feet of All Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	230	213.52	171	NO	257	NO
Personal Injury	73	43.43	30	NO	58	YES
Fatal	0	4.53	0	NO	11	NO

Table 5-11: Summary Statistical Calculations for Crashes Within 500 feet of All Intersections.

	Predicted Value, $\Sigma a_{0A}$	Predicted Variance, $\Sigma \text{var } a_{0A}$	Variability, $\alpha$	$s = 1/\alpha$	$p=1/(1+\alpha*\Sigma a_{0A})$
Rear End, Neither Turning	87.34	298.89	0.039	25.52	0.226
Head On, Neither Turning	1.67	1.63	0.582	1.72	0.506
Same Direction Sideswipe	16.87	64.14	0.226	4.43	0.208
Opposite Direction Sideswipe	2.66	2.68	0.379	2.64	0.498
Off Road Collision	0.50	0.25	1.000	1.00	0.668
Right Angle	77.66	276.12	0.046	21.84	0.220
Left and Right Turns	0.00	0.00	INSUFFICIENT DATA		
Left Turn	12.69	26.29	0.163	6.12	0.325
Right Turn	19.69	121.73	0.314	3.18	0.139
Other / Unknown	42.41	223.32	0.124	8.05	0.160
Total	261.48	1015.04	0.015	67.36	0.205
Property Damage	213.52	925.18	0.020	49.28	0.188
Personal Injury	43.43	73.51	0.039	25.66	0.371
Fatal	4.53	16.35	0.797	1.25	0.217

Each test was also performed for 200 feet and 1000 feet data sets. Table 5-12 and Table 5-13 show the results of the tests for crashes within 200 feet of the intersections. At this distance, 'Right Angle' and 'Right Turn' are statistically significant for improvement after traffic signal installation. 'Rear End, Neither Turning', 'Head On, Neither Turning', 'Off Road Collision', and 'Left Turn' are statistically significant for degradation after signal installation. Results of these tests for crash types are in Table 5-12. The tests on severity of crashes, in Table 5-13, show that 'Personal Injury' passes Test 2 and there is significant degradation after signal installation.

Table 5-12: Results Table for Crash Types Within 200 feet of All Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	129	82.07	58	NO	108	<b>YES</b>
Head On, Neither Turning	7	1.18	0	NO	3	<b>YES</b>
Same Direction Sideswipe	11	16.87	7	NO	29	NO
Opposite Direction Sideswipe	2	2.24	0	NO	5	NO
Off Road Collision	4	0.50	0	NO	2	<b>YES</b>
Right Angle	46	76.48	54	<b>YES</b>	101	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	27	11.51	5	NO	20	<b>YES</b>
Right Turn	0	19.17	6	<b>YES</b>	35	NO
Other / Unknown	64	42.41	23	NO	64	NO
Total	291	252.42	208	NO	299	NO

Table 5-13: Results Table for Severity of Crashes Within 200 feet of All Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	224	210.74	168	NO	255	NO
Personal Injury	67	37.15	25	NO	51	<b>YES</b>
Fatal	0	4.53	0	NO	11	NO

Table 5-14 and Table 5-15 are summary tables for tests performed on crashes within 1000 feet of the intersection. For Test 1, 'Right Angle' and 'Right Turn' are statistically significant for improvement after traffic signal installation. 'Rear End, Neither Turning', 'Off Road Collision', Left Turn', and 'Other/Unknown' are statistically significant for degradation after signal installation. The same tests are performed on these crashes for severity of crashes at 1000 feet from the intersection and 'Personal Injury' is significant for degradation after signal installation.

Table 5-14: Results Table for Crash Types Within 1000 feet of All Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	135	94.46	69	NO	121	<b>YES</b>
Head On, Neither Turning	7	5.68	1	NO	12	NO
Same Direction Sideswipe	15	16.87	7	NO	29	NO
Opposite Direction Sideswipe	2	2.66	0	NO	6	NO
Off Road Collision	5	0.50	0	NO	2	<b>YES</b>
Right Angle	51	78.32	55	<b>YES</b>	103	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	28	12.69	5	NO	21	<b>YES</b>
Right Turn	0	19.69	7	<b>YES</b>	36	NO
Other / Unknown	66	42.41	23	NO	64	<b>YES</b>
Total	310	273.27	227	NO	320	NO

Table 5-15: Results Table for Severity of Crashes Within 1000 feet of All Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	235	223.26	180	NO	268	NO
Personal Injury	74	47.44	33	NO	63	<b>YES</b>
Fatal	0	4.53	0	NO	11	NO

Crashes at each intersection were tested at three distances, 200, 500, and 1000 feet from the intersection. The two tests show if there is any significant improvement or degradation after a traffic signal installation. Table 5-16 is a summary table of results for each test at each distance. From the results, 'Right Angle' and 'Right Turn' are consistently significant for improvement after signal installation at each distance. As for being statistically significant for degradation, 'Rear End, Neither Turning', 'Off Road Collision', 'Left Turn' and 'Personal Injury' are significant at each distance. 'Head On, Neither Turning' is significant for degradation at distances 200 feet and 500 feet from the intersection. 'Other/Unknown' is statistically significant for degradation at 500 feet and 1000 feet.

Table 5-16: Summary Table of Results for Test 1 and Test 2 for Distances 200 feet, 500 feet, and 1000 feet from All Intersections.

	Significant Safety Improvement with Signal Installation			Significant Safety Degradation with Signal Installation		
	Distance From Intersection			Distance From Intersection		
	200 feet	500 feet	1000 feet	200 feet	500 feet	1000 feet
Rear End, Neither Turning				✓	✓	✓
Head On, Neither Turning				✓	✓	
Same Direction Sideswipe						
Opposite Direction Sideswipe						
Off Road Collision				✓	✓	✓
Right Angle	✓	✓	✓			
Left and Right Turns						
Left Turn				✓	✓	✓
Right Turn	✓	✓	✓			
Other / Unknown					✓	✓
Total						
Property Damage						
Personal Injury				✓	✓	✓
Fatal						

#### 5.6. School Zone Intersection Analysis

The results of an analysis on intersections located at school zones are shown in the following section. The same analysis testing procedure described previously in this section was applied to this data subset (Only intersections 1, 2, 3, 9, 10, 16, 17). Counts for crash types at these

intersections are given in Table 5-17. The sample size is smaller than the previous analysis with 58 before installation crashes and 64 after installation crashes. From the smaller sample size, the crashes are also categorized in severity of crashes in Table 5-18.

Table 5-17: Summary Table of Crash Type Counts at School Zone Intersections Within 500 feet of the Intersection.

Intersection	Counts by Crash Types																											
	Years		Rear End, Neither Turning		Head On, Neither Turning		Same Direction Sideswipe		Opposite Direction Sideswipe		Off Road Collision		Right Angle		Left and Right Turns		Left Turn		Right Turn		Other / Unknown		Total					
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After				
1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1				
2	5	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	7				
3	5	2	6	4	1	0	5	1	0	0	1	0	1	1	0	0	2	0	1	0	4	1	21	7				
9	4	4	9	6	1	1	1	0	0	0	0	1	10	10	0	1	1	7	2	0	4	3	28	29				
10	5	2	0	3	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7			
16	3	5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
17	5	2	1	4	0	1	0	1	1	0	0	0	5	2	0	0	0	2	0	0	0	2	7	12				
<b>Total</b>	<b>32</b>	<b>19</b>	<b>18</b>	<b>20</b>	<b>2</b>	<b>4</b>	<b>6</b>	<b>5</b>	<b>1</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>16</b>	<b>14</b>	<b>0</b>	<b>1</b>	<b>3</b>	<b>9</b>	<b>3</b>	<b>0</b>	<b>8</b>	<b>9</b>	<b>58</b>	<b>64</b>				

Table 5-18: Summary Table of Severity of Crashes at School Zone Intersections Within 500 feet of the Intersection.

Intersection	Severity of Crashes							
	Years		Property Damage		Personal Injury		Fatal	
	Before	After	Before	After	Before	After	Before	After
1	5	2	1	0	1	1	0	0
2	5	2	0	5	0	2	0	0
3	5	2	17	6	4	1	0	0
9	4	4	19	24	9	5	0	0
10	5	2	0	4	0	3	0	0
16	3	5	0	0	0	0	0	0
17	5	2	3	9	4	3	0	0
<b>Total</b>	<b>32</b>	<b>19</b>	<b>40</b>	<b>48</b>	<b>18</b>	<b>15</b>	<b>0</b>	<b>0</b>

Along with the same categorization of crashes, a new change in exposure to risk is calculated. Again, the adjustment to exposure is the product of ratio of years and ratio of AADT. The resulting change in exposure to risk is calculated in Table 5-19.

Table 5-19: Summary Table of Change in Exposure to Risk for School Zone Intersections.

Intersection	Installation Year	Years			Annual Average Daily Traffic								
		Years Before, $Y_B$	Years After, $Y_A$	Adjusted Year Rate $Y_A/Y_B$	Year	AADT (vehicle/day)	Year	AADT (vehicle/day)	Growth rate	Before Year Midpoint	After Year Midpoint	Adjusted AADT Rate, $AADT_A/AADT_B$	Combined Exposure To Risk, E, Year and AADT, $(E_A/E_B)$
1	1997	5	2	<b>0.40</b>	1995	12560	1999	13190	1.012	1994	1998	<b>1.05</b>	<b>0.42</b>
2	1997	5	2	<b>0.40</b>	1995	9490	1999	9030	0.988	1994	1998	<b>0.95</b>	<b>0.38</b>
3	1997	5	2	<b>0.40</b>	1995	6930	2000	9110	1.056	1994	1998	<b>1.24</b>	<b>0.50</b>
9	1995	4	4	<b>1.00</b>	1995	8720	1999	9930	1.033	1992	1997	<b>1.18</b>	<b>1.18</b>
10	1997	5	2	<b>0.40</b>	1990	14010	1996	19420	1.056	1994	1998	<b>1.24</b>	<b>0.50</b>
16	1994	3	5	<b>1.67</b>	1992	24420	1996	27820	1.033	1992	1997	<b>1.18</b>	<b>1.96</b>
17	1997	5	2	<b>0.40</b>	1993	38090	1998	40620	1.013	1994	1998	<b>1.05</b>	<b>0.42</b>

The same calculations are used to determine the aggregate predicted after crash values. The change of exposure to risk was multiplied to the observed before crashes and then totaled for the aggregate sum. This procedure is applied to each crash type and severity. The aggregate predicted values are then compared to critical values calculated from the negative binomial distribution. Test 1 and Test 2 are used to compare these values.

The results of these tests on crash types within 500 feet of the intersection are in Table 5-20. 'Head On, Neither Turning', 'Off Road Collision', 'Left Turn' and 'Total' are statistically significant for degradation after the signal installation. There are no statistically significant improvements for any crash types at 500 feet.

Table 5-20: Results Table for Crash Types Within 500 feet of School Zone Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	20	14.84	8	NO	22	NO
Head On, Neither Turning	4	1.67	0	NO	4	<b>YES</b>
Same Direction Sideswipe	5	3.67	1	NO	7	NO
Opposite Direction Sideswipe	0	0.42	0	NO	1	NO
Off Road Collision	2	0.50	0	NO	2	<b>YES</b>
Right Angle	14	14.37	8	NO	22	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	9	2.17	0	NO	5	<b>YES</b>
Right Turn	0	2.85	0	NO	6	NO
Other / Unknown	9	6.70	2	NO	12	NO
Total	64	47.18	35	NO	60	<b>YES</b>

Table 5-21 shows the results of the same tests on severity of crashes within 500 feet. Degradation for 'Property Damage' is statistically significant. For this data set, 'Fatal' and 'Left and Right Turns' do not have sufficient data to determine and significant changes of safety.

Table 5-21: Results Table for Severity of Crashes Within 500 feet of School Zone Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	48	32.50	23	NO	43	<b>YES</b>
Personal Injury	15	14.68	8	NO	22	NO
Fatal	0	0.00	INSUFFICIENT DATA			

The tests are also applied to crashes at school zone intersections for 200 feet and 1000 feet from the intersection. In Table 5-22, results from the tests on crash types for crashes within 200 feet show that 'Rear End, Neither Turning', 'Head On, Neither Turning', 'Left Turn', and 'Total' are statistically significant for safety degradation after signal installation. At this distance, there is insufficient data for 'Off Road Collision', along with 'Left and Right Turns'. Table 5-23 is a table of results for the tests on severity of crashes at 200 feet. Again, 'Fatal' does not have sufficient data for a test, while 'Property Damage' is found to be significant for degradation.

Table 5-22: Results Table for Crash Types Within 200 feet of School Zone Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	18	10.89	5	NO	17	<b>YES</b>
Head On, Neither Turning	4	1.18	0	NO	3	<b>YES</b>
Same Direction Sideswipe	5	3.67	1	NO	7	NO
Opposite Direction Sideswipe	0	0.00	INSUFFICIENT DATA			
Off Road Collision	1	0.50	0	NO	2	NO
Right Angle	13	13.19	7	NO	20	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	9	1.00	0	NO	3	<b>YES</b>
Right Turn	0	2.85	0	NO	6	NO
Other / Unknown	8	6.70	2	NO	12	NO
<b>Total</b>	<b>59</b>	<b>39.96</b>	<b>29</b>	<b>NO</b>	<b>52</b>	<b>YES</b>

Table 5-23: Results Table for Severity of Crashes Within 200 feet of School Zone Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	46	30.90	21	NO	41	<b>YES</b>
Personal Injury	13	9.06	4	NO	14	NO
Fatal	0	0.00	INSUFFICIENT DATA			

Crashes at school zones intersection within 1000 feet were then tested for significant changes after traffic signal installation. Table 5-24 is a results table for crash types at this distance. These results are similar to the one at 500 feet. 'Head On, Neither Turning', 'Off Road Collision', 'Left Turn', and 'Total' are found to be statistically significant for degradation. Again, there are no statistically significant improvements at this distance at school zone intersection.

Table 5-24: Results Table for Crash Types Within 1000 feet of School Zone Intersections.

Type of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Rear End, Neither Turning	20	14.84	8	NO	22	NO
Head On, Neither Turning	4	1.67	0	NO	4	<b>YES</b>
Same Direction Sideswipe	5	3.67	1	NO	7	NO
Opposite Direction Sideswipe	0	0.42	0	NO	1	NO
Off Road Collision	2	0.50	0	NO	2	<b>YES</b>
Right Angle	14	14.37	8	NO	22	NO
Left and Right Turns	1	0.00	INSUFFICIENT DATA			
Left Turn	9	2.17	0	NO	5	<b>YES</b>
Right Turn	0	2.85	0	NO	6	NO
Other / Unknown	9	6.70	2	NO	12	NO
Total	64	47.18	35	NO	60	<b>YES</b>

Results for severity of crashes within 1000 feet of school zone intersection are similar to previous results for crash severity at school zone intersections. Table 5-25 shows the results of the two tests on severity of crashes. 'Property Damage' is found to be statistically significant for

degradation after the traffic signal installation. Results for 'Fatal' are not able to be calculated due to insufficient data.

Table 5-25: Results Table for Severity of Crashes Within 1000 feet of School Zone Intersections.

Severity of Crashes	Actual Value, $a_A$	Predicted Value, $a_{0A}$	Low Critical Value @ 10%	Test 1, Test if Significant Improvement	High Critical Value @ 10%	Test 2, Test if Significant Degradation
Property Damage	48	34.46	24	NO	45	<b>YES</b>
Personal Injury	15	14.68	8	NO	22	NO
Fatal	0	0.00	INSUFFICIENT DATA			

School zone intersections were tested for any statistical significant changes due to a traffic signal intersection for crashes within 200, 500, and 1000 feet from the intersection. Table 5-26 summarizes the results from these tests. For these intersections, there are no significant safety improvements due to signal installation. Crash types; 'Head On, Neither Turning' 'Left and Right Turns' and 'Total' are statistically significant for degradation at each distance. Crash severity 'Property Damage' degrades significantly also at these distances. 'Rear End, Neither Turning' is significant for degradation for crashes within 200 feet of the intersection. 'Off Road Collision" is found to be statistically degrading for distances of 500 and 1000 feet from school zone intersections.

Table 5-26: Summary Table of Results for Test 1 and Test 2 on School Zone Intersection for Distances 200 feet, 500 feet, and 1000 feet from the Intersection.

	Significant Safety Improvement with Signal Installation			Significant Safety Degradation with Signal Installation		
	Distance From Intersection			Distance From Intersection		
	200 feet	500 feet	1000 feet	200 feet	500 feet	1000 feet
Rear End, Neither Turning				✓		
Head On, Neither Turning				✓	✓	✓
Same Direction Sideswipe						
Opposite Direction Sideswipe						
Off Road Collision					✓	✓
Right Angle						
Left and Right Turns						
Left Turn				✓	✓	✓
Right Turn						
Other / Unknown						
Total				✓	✓	✓
Property Damage				✓	✓	✓
Personal Injury						
Fatal						

## CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

### 6.1. Summary of Results

A total of 19 intersections were selected and analyzed to show the effects of minimally warranted signal installation. Of these 19 intersections, seven signals are located adjacent to school zones. For each intersection, crash data was obtained for up to five years before and five years after signal installation. Installation year was not included in the analysis so that any crashes associated with the construction work zone would not bias the data. This data was adjusted for Exposure to Risk to account for changes in average daily traffic and the varying number of before and after data years. Data was evaluated at three different study areas, 200 feet, 500 feet, and 1000 feet from the intersections. Crash data was also categorized by type and severity. From this data, negative binomial tests were used to determine if there were any significant changes due to signal installation. The first test was used to evaluate any significant safety improvements while the second test evaluated significant safety degradation. These tests were used for each of the 19 intersections and then only for the seven school zone intersections.

Results of the tests on all of the 19 intersections show that there was a significant safety improvement for the crash types 'Right Angle' and 'Right Turn'. There was also significant safety degradation for the crash types 'Rear End, Neither Turning', 'Head On, Neither Turning' (for 200 feet and 500 feet only), 'Off Road Collision', 'Left Turn', and 'Other/Unknown' (for 500 feet and 1000 feet only). Crash severity 'Personal Injury' was also found to be significant for degradation.

Tests on the seven intersections at school zones resulted in no significant safety improvements. 'Head On, Neither Turning', 'Left Turn', 'Total', and 'Property Damage' were found to have significant safety degradation. 'Rear End, Neither Turning' was found to be significant for degradation at 200 feet and 'Off Road Collision' was found to be significant for degradation at distances of 500 feet and 1000 feet.

These results do not indicate that it is beneficial to install traffic signals in school zones when the warrants defined by the Manual on Uniform Traffic Control Devices have not been met. In fact,

they suggest that for intersections not meeting the warrants, traffic signals should not be installed. Based upon these findings, it is recommended that the Indiana Department of Transportation continue following nationally prescribed warrants for determining when a traffic signal should be installed.

## 6.2. Traffic Signal Alternatives

During the research, three school zones were identified for further study. The following schools have requested signal installation at adjacent intersections.

- Kanakakee Valley High School in Wheatfield, Indiana,
- Northview High School in Brazil, Indiana,
- Delphi Community High School in Delphi, Indiana

### 6.2.1. Kankakee Valley High School

Kankakee Valley High School is located in Wheatfield, Indiana at the intersection of SR-10 and CR-400W. This intersection is two-way stop controlled with a flashing beacon. There are approximately 1800 students and 200 faculty and staff. Of the 1800 students, there are an estimated number of 150 student drivers. Along with the student and staff drivers, there are 20-30 school buses that service the high school and adjacent middle school.

As noted in Chapter 2, the intersection at Kankakee Valley High School did not meet any of minimum requirements of the traffic warrants. After multiple requests for signal installation, INDOT had recommended alternative methods of traffic control. This included the use of an 'Advance School Flasher' warning signs at the school's expense. The school corporation has implemented these alternatives.

### 6.2.2. Northview High School

This school is located in Brazil, Indiana at the intersection of SR-340 and Kennedy's Crossing Road. The intersection is controlled with a one-way stop on Kennedy's Crossing Rd. The school currently has approximately 1,300 staff and students. There is also a middle school next to the high school which is connected by an interior road, seen in Figure 6-1. For these two schools, there are 28 school buses servicing the students. Along with school buses, there are approximately 400 student drivers.



Figure 6-1: Aerial view of Clay County schools in Brazil, Indiana.

Northview High School has also requested and been denied for signal installation at the adjacent intersection. At the time of dismissal, there is an increase of vehicular volume. Since INDOT did not install a traffic signal, the Transportation Department for Clay County Schools began in April 2000 to use a reserve police officer to direct traffic flows. It has been documented that there had been seven crashes in 1998, six crashes in 1999, and three crashes in 2000. Since the police officer began directing traffic, there have not been any reported crashes at the intersection. There is an officer at the intersection each school day and when he is not able to be there, the Director of Transportation for Clay County Schools, Frank Misner has substituted. Currently, the

school corporation pays for the officer's salary of \$10,000 per year, but is concerned that there will not be sufficient funds to continue the use of the reserve police officer. The school corporation continues to request signal installation.

### 6.2.3. Delphi Community High School

Delphi Community High School is located in Delphi, Indiana at the intersection of US-421 and Armory Road. The intersection is controlled by a two-way stop sign and a flashing beacon as seen in Figure 6-2. Approach speeds are posted at 35 mph with no school zone warning signs. Current enrollment is 500 students with 70 faculty and staff. Traffic volumes include approximately 20 school buses and 150 student drivers.

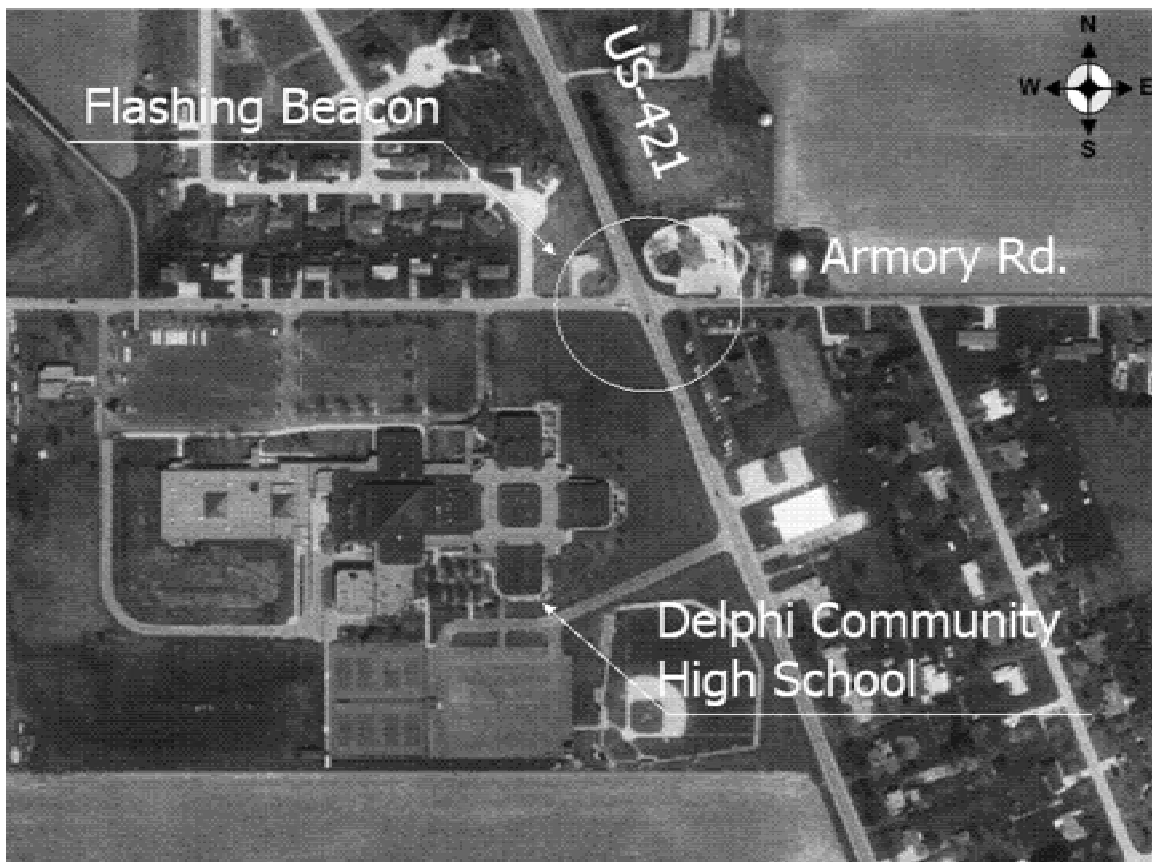


Figure 6-2: Aerial view of Delphi Community High School in Delphi, Indiana.

Over the past ten years, there have been multiple requests for signal installation at the intersection. INDOT has denied their requests, citing that the vehicular volume does not meet minimum requirements for traffic signal warrants. In response to these denials, city and county police officers have volunteered to direct traffic at the intersection. Observations show that there is a staggered time when the students and school buses leave. The students leave shortly after dismissal and the school buses wait until the police officer comes and directs traffic. This began in 1999 with city police officers coming to the intersection during afternoon dismissal. At first, police participation was low, but increased when the county police office took control of the responsibility. Currently the Carroll County Sheriff, Denny Randle, arrives during the afternoon dismissal time and directs traffic. According to the Delphi Community High School principal, Bob Handlin, there has been an officer at the intersection close to 99% of the time. The only times when there no officer directing traffic is during early dismissal times and when the officer is called away on police duty. The police department did not want school employees to direct traffic if an officer does not arrive at the intersection. This duty is on a volunteer basis and officers are not paid with incentives. When an officer is not present, bus drivers use an alternative route taking them away from US-421 and utilizing local streets. The school corporation continues to request for signal installation.

### 6.3. Future Work

Although this study found that the installation of traffic signals at minimally warranted signals would not improve safety, there is still a need to find other methods of traffic control. Based upon anecdotal reports, one of the most effect procedures appears to be the use of law enforcement personnel to direct traffic during peak periods. Further work should be undertaken defining procedures, policies, and funding alternatives for school districts to follow should they choose to have traffic manually controlled during peak periods.

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## APPENDIX

## APPENDIX A. CRASH TYPE DEFINITIONS

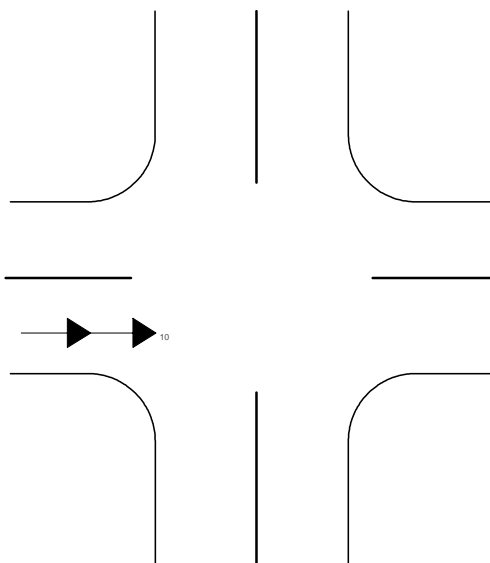


Figure A-1:

'Rear End, Neither Turning' – These crashes are characterized when one vehicle collides with another from behind as seen.

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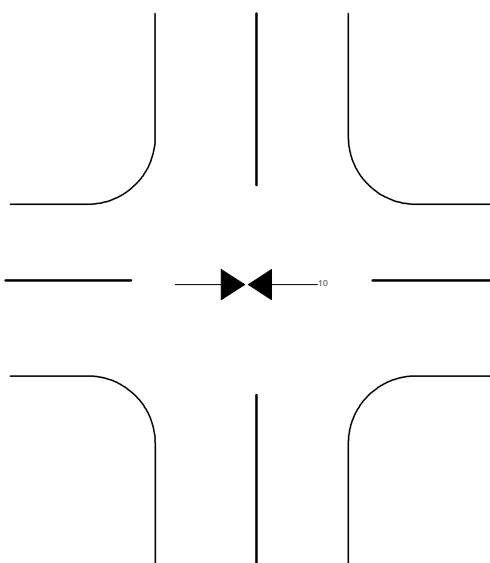


Figure A-2:

'Head On, Neither Turning' – These crashes involve vehicles traveling in opposite directions and colliding with each other head on. This crash occurs when one vehicle crosses the median into the other lane.

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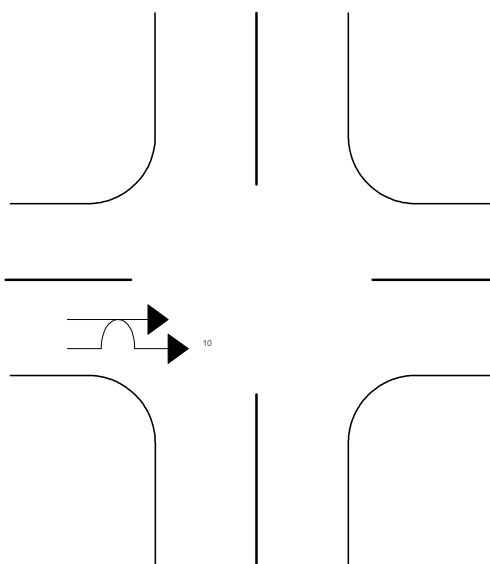


Figure A-3:

'Same Direction Sideswipe' – These crashes occur when a vehicle attempts to pass another vehicle. There are two typical situations, when a vehicle tries to pass a turning vehicle, or when a vehicle crosses into the adjacent lane.

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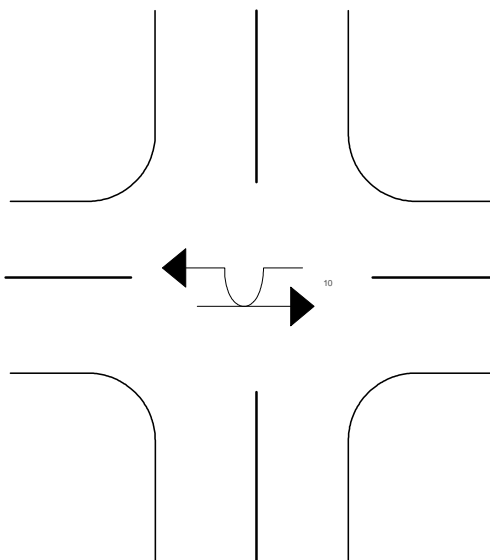


Figure A-4:

'Opposite Direction Sideswipe' – Crashes are categorized as 'Opposite Direction Sideswipe' when a vehicles traveling in opposite directions collide. These crashes are similar to 'Head On, Neither Turning', but the collision point is different.

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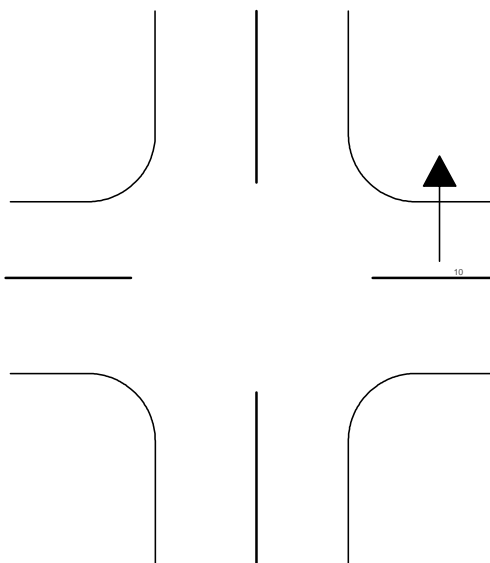


Figure A-5:

'Off Road Collision' –These crashes occur when a vehicle is avoiding something on the roadway, or the driver loses control of the vehicle.

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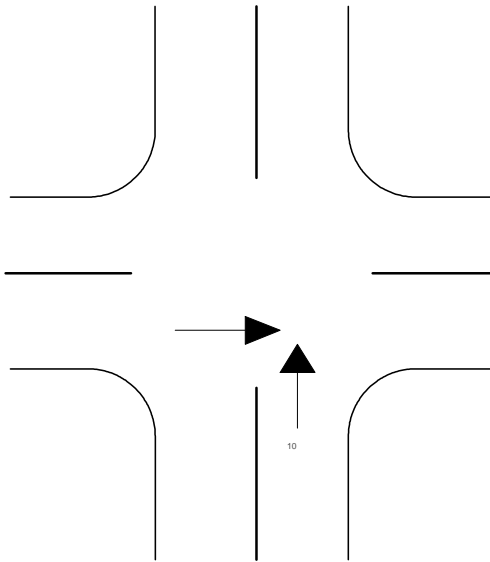


Figure A-6:

'Right Angle' – This category involves accidents where vehicles are typically crossing a roadway, but does not judge the gap correctly and is hit by the oncoming vehicle.

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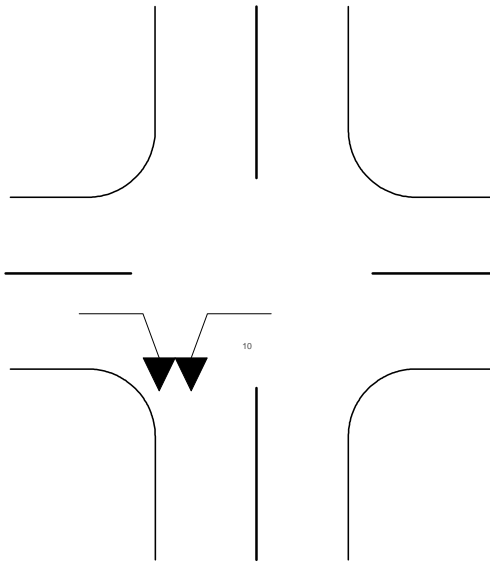


Figure A-7:

'Left and Right Turns' – These crashes occur when a vehicle is turning right and another vehicle turning left. This can occur if either vehicle becomes hasty and does not allow for enough distance for the vehicle to complete their turn.

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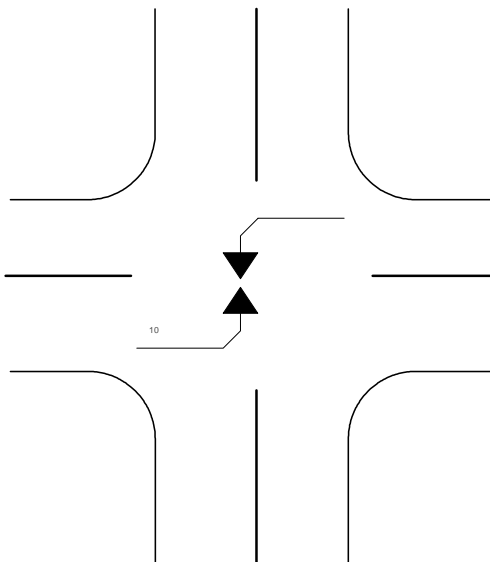


Figure A-8:

'Left Turn' – This is a crash diagram of one example of a 'Left Turn' that shows a crash with two vehicles that are turning left at the same time.

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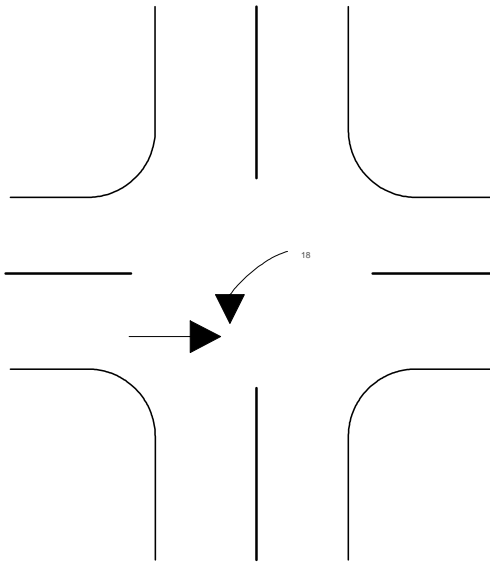


Figure A-9:

'Left Turn' – This is a crash diagram of another example of a 'Left Turn' that occurs when a vehicle turns left in front of an oncoming vehicle.

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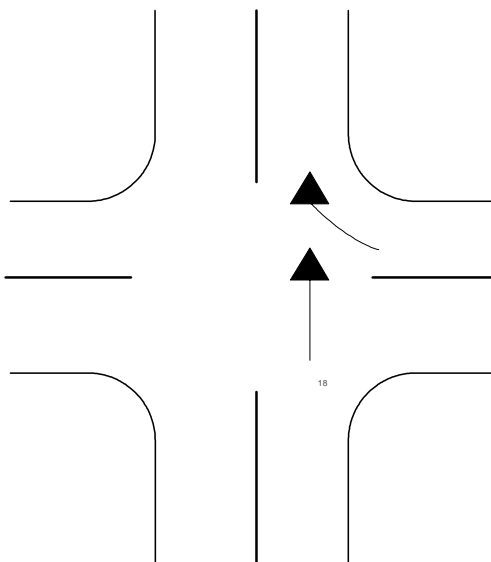


Figure A-10:

**'Right Turn'** – Crashes are categorized 'Right Turn' when the cause of the crash is a result of one of the vehicles is turning right. A typical scenario for this type of crash occurs when a vehicle turns right in front of an oncoming vehicle. Another typical situation for this type of crash is when a vehicle slows down to turn right and the vehicle behind it collides into the vehicle ahead.

**'Other/Unknown'** – These crashes are due to the lack of information within police crash reports. A crash could be put into this category if a police officer does not provide the information, or if there are external reasons causing the crash.