ANALYSIS AND EVALUATION OF THE PEDESTRIAN HYBRID BEACON IN SCHOOL ZONES

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Analysis and Evaluation of the Pedestrian

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

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Meeting dual objectives of pedestrian safety and motorist convenience at pedestrian crossings in school zones is an important and continuing challenge for all local communities. Pedestrian safety is influenced by pedestrian delays as well as motorist compliance of controls. Motorist convenience is influenced by the delay experienced by drivers. Conventional crosswalk control devices such as marked crosswalks and pedestrian signals are not always adequate or efficient in balancing these two crucial but conflicting objectives. The 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD) has paved the way for the use of a brand new crosswalk control device known as the pedestrian hybrid beacon (PHB). Previous research has provided evidence of this device's effectiveness in the area of motorist compliance and reduced motorist delay compared to traditional pedestrian signals. No prior research has been conducted on the PHB in the school zone context or on children pedestrians in general.

This research has two objectives. The first objective was to analyze MUTCD Warrant 5 standards, which are designed for pedestrian signals in school zones, and the new PHB standards. This analysis will use pedestrian volume, vehicle volume, and gap availability on different test locations to conduct a comparative analysis of the two sets of standards. The purpose of this objective is to determine the transferability of the new MUTCD PHB standards in the school zone context. The second objective of this research was to evaluate three crosswalk control devices; marked crosswalks, pedestrian signals, and PHBs, for their ability to effectively address pedestrian safety and motorist convenience at school crossings.

It was found that the PHB performed significantly better than traditional marked crosswalks but not markedly different than conventional pedestrian signals in the ability to balance the objectives of pedestrian safety and motorist convenience. The absence of improvements in performance of the PHB when compared to the pedestrian signal can be attributed to the fact that only 8.8% of motorists correctly utilized the PHB at the test location in Fargo, North Dakota. The most significant contribution of this thesis was finding that the current PHB standards in MUTCD are not transferable to the school zone context. For PHBs to be considered a viable option for engineers designing and controlling school crosswalks, it is essential that the MUTCD have school zone specific standards or guidance. The analysis carried out in this research provides insights into how such standards can be established and applied.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

This introduction chapter will lay the foundation for the rest of the thesis and cover background information regarding pedestrian safety, traffic statistics, conventional crosswalk control devices such as crosswalk markings, pedestrian signs, and traffic control devices, as well as a recently introduced device known as the pedestrian hybrid beacon (PHB). From this background knowledge is drawn the following: the problem statement, the objectives, and the scope.

1.1. Pedestrian Safety and Traffic Statistics

Pedestrian safety at crosswalk locations is a critical design consideration for engineers. According to federal data, a pedestrian is killed in a traffic crash in the United States every 110 minutes and one is injured every 9 minutes (Copeland, 2008). This is a major concern among younger, less experienced pedestrians. In 2007, 1 out of every 5 pedestrians injured in a vehicle collision was of age 14 or younger. Even more concerning is that almost eighty percent of the pedestrian fatalities among the 14-and-younger age group occurred at non-intersection/midblock locations (NHTSA, 2007). Table 1.1 highlights the dangers that midblock crossings can cause for young pedestrians.

Table 1.1. Pedestrian Fatalities Percentage by Junction Type and Age

	Age					
Junction Type	≤12	13-19	20-34	35-59	60-69	≥70
Non-Intersection	77%	79%	84%	79%	68%	64%
Intersection	23%	21%	16%	21%	32%	36%

Source: Insurance Institute for Highway Safety, 2006

According to the U.S. Centers for Disease Control and Prevention, dangerous traffic conditions is the number two barrier preventing children from walking to school, second only to distance (U.S. Centers for Disease Control and Prevention, 2005). Due in part to the unsafe environment typical school routes pose, parents are choosing to drive their children to school instead of allowing them to walk. The use of automobiles for transportation to/from school has increased from 16% in 1969 to 46% in 2001 and accounts for over one-fifth of morning traffic during the school year (Kallis, 2010). This increase in traffic flow has helped lead to traffic congestion problems in the United States. Due to overall traffic congestion, the national total hours of motorist delay has increased by over 500% between 1982 and 2002 (Schrank and Lomax, 2005).

In addition to alleviating current traffic congestion problems, the simple act of walking can be beneficial for health purposes as well. According to the American Association of Retired Persons (AARP); people who walk regularly reduce the risk of life threatening health problems such as stroke, heart disease, colon cancer, and diabetes (AARP, 2009). Physical activity such as walking also improves mental health and is important for the health of muscles, bones, and joints. Through a modest increase in daily activity, most Americans can improve their well-being and quality of life (U.S. Department of Health and Human Services, 1996).

To promote walking, engineers should strive to create a street environment that is safe for pedestrians. Sidewalks and street crossings should be free of hazards and should minimize conflicts with vehicular traffic. Designing safe street crossings can be difficult for unique locations such as school zones. The difficulty in designing school zones arises from the unpredictable nature of elementary and middle school aged children. When deciding whether to cross the street, children of this age have a tendency to dart out into the street instead of waiting for vehicles to pass (PBIC, 2009). Careful design of the places children walk most, such as school zones, school walking routes, and neighborhood streets can significantly help reduce the risk that young pedestrians pose. Typical design alternatives that engineers utilize to create safer pedestrian crossings include pavement markings, pedestrians crosswalk signs, and pedestrian signals where warranted (FHWA, 2005[1]).

1.2. Conventional Crosswalk Control Methods

A pedestrian crosswalk is a specially paved or marked path across a roadway designed to keep pedestrians together where they can be seen by motorists, and where they can cross most safely with the flow of vehicular traffic (PBIC, 2009). Crosswalks are also marked where significant pedestrian concentrations occur, where traffic movements are controlled, and where there is substantial conflict between vehicle and pedestrian movements (FHWA, 2005[2]). They are common near schools or in other areas where there are a large number of children (SRTS, 2009). Marking a crosswalk can be a significant way to improve pedestrian safety and make it easier to cross the roadway.

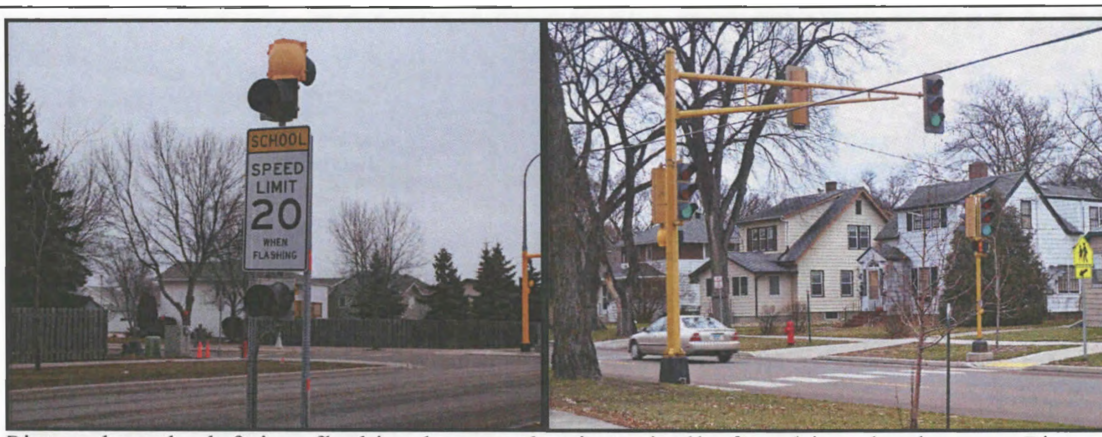
Generally wherever crosswalks are marked, a complimenting sign can be found. Signs can provide important information that can improve road safety. By letting people know what to expect, there is a greater chance that they will react and behave appropriately (ITE, 1998). Advanced pedestrian warning signs should be used where pedestrian crossings may not be expected by motorists, especially if there are many motorists who are unfamiliar with the area (FHWA, 2002). Signs should only be used when the legal requirement is not otherwise apparent. Unnecessary signs can cause visual clutter, represent a hazard to errant motorists, and may cause an obstruction to pedestrians and bicyclists (FHWA, 2004).

While every attempt should be made to cross pedestrians at intersections, pedestrians tend to cross at locations that are most convenient to them (Schroeder, 2008). As a result, midblock crossings are a necessary pedestrian movement in many urban, suburban and rural locations (see Figure 1.1). Contrary to what is implied in the terminology, these crossings are not necessarily located in the middle of a block, but rather can be found anywhere along a roadway at locations away from an intersection crossing. Determining if a midblock crossing should be marked or unmarked must be carefully considered. If the midblock crossing is poorly designed, then it will violate driver expectancy and could cause safety problems for pedestrians. When drivers expect pedestrians at certain locations, they are much more likely to stop for them. This in-turn makes these locations much safer (FHWA, 2005[2]).

Picture on the left is a standard marked and signed crosswalk taken at the intersection of 28th St. and 40th Ave. S Fargo. Pictured on the right is a standard marked midblock crosswalk taken at the intersection of a bike path between 17th and 18th St. and 37th Ave. S.

Figure 1.1. Marked Crosswalks.

Marked crosswalks at intersection and mid-block locations can also be signalized (see Figure 1.2). The installation of a traffic control signal requires that the crosswalk meet one of the Manual on Uniform Traffic Control Devices (MUTCD) nine warrants, whereas crosswalk markings and pedestrian signs can be installed based on discretion. An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location must be performed to determine if the location falls under a particular warrant and justifies the installation of a traffic control signal (FHWA, 2009). Seven of these nine warrants deal with controlling vehicular traffic with respect to vehicular volume, progressive movements in coordinated signal systems, crash experience, scenarios where concentration and organization of traffic flow is required, or for special grade crossings. In contrast, Warrants 4 and 5 deal with controlling vehicular traffic with respect to pedestrian safety. Specifically, Warrant 5 is intended for application at locations where a school child crossing the major street is the principal reason to consider installing a traffic control signal. This will be the warrant of focus in this thesis due to the correlation to school crossings. Warrant 5 will be discussed in greater detail in Chapter 3. Other warrants are beyond the scope of this thesis, but can be further reviewed at the MUTCD website (mutcd.fhwa.dot.gov).



Pictured on the left is a flashing beacon that is typically found in school zones. Picture was taken on 40th Avenue S. adjacent to Centennial Elementary School. Pictured on the right is a standard marked and signalized midblock school crossing. Picture was taken on 2nd St. N between 10th and 11th Ave N adjacent to Horace Mann Elementary School

Figure 1.2. School Zone Crosswalks.

As stated earlier, elementary and middle school aged children can be unpredictable at crossing locations. Due to this high risk of unpredictability, school crossings should be handled with increased sensitivity and appropriate precautionary measures should be considered (PBIC, 2009). General precautionary measures consist of marked crosswalks, pedestrian signs, pedestrian signals, and/or flashing beacons. Flashing beacons are used to alert motorists of reduced speeds during specific school related times.

1.3. Pedestrian Hybrid Beacon Background Information

The 2009 edition of the MUTCD has many new additions and updates, but one of the most significant is the institution of a new crosswalk control device known as the pedestrian hybrid beacon (PHB). This new device adds another crosswalk control option to consider when designing for pedestrians at midblock locations. The MUTCD defines the pedestrian hybrid beacon as a special type of hybrid beacon used to warn and control traffic at an unsignalized location. These beacons are used to assist pedestrians in crossing a street or highway (FHWA, 2009). These signals can be instituted without passing one of the nine MUTCD warrants, but must pass MUTCD standards that are specified for these devices. It is important to note that the opposite is true as well: under section 4F.06 of the 2009 MUTCD PHBs can be installed if they meet one of the nine standard warrants. MUTCD standards regarding PHBs can be further reviewed in Appendix A.

The pedestrian hybrid beacon was first instituted by the DOT of Tuscon, Arizona in 1998 and was referred to as the HAWK signal. The acronym HAWK stands for High-intensity Activated cross-WalK (PBIC, 2002). According to city of Fargo officials, these beacons are not considered signals because the PHB goes dark when it is not active and, by law, you are required to stop at all signals that are dark and treat them as an all-way stop.

The PHB is pedestrian activated. Once the push-button is pressed by a pedestrian, a standardized green time for the vehicular movements is in effect until the signal is activated. The signal doesn't physically have a green light so the standard green time refers to the time the signal remains dark until activated. Once the signal becomes active it begins by flashing yellow for several seconds then changes to solid yellow for the standard Institute of Transportation Engineers (ITE) calculated length of time, which is between three and six seconds (ITE, 1998). Next, the two red indications illuminate and the pedestrian signal displays a WALK indication. At the end of the WALK phase, the red signals alternate back-and-forth, corresponding with the pedestrian signal flashing DON'T WALK phase. This alternating phase is similar to a flashing red indication at a signalized intersection. Drivers need to stop and give the right-of-way to the conflicting stream, which in this case is the crossing pedestrian or group of pedestrians. After the pedestrian(s) have cleared the travel path of the vehicle, drivers can proceed with caution and do not have to wait for the entire flashing DON'T WALK clearance interval to elapse as they would at a conventional pedestrian activated signal. The PHB then goes dark and the pedestrian signal returns to solid DON'T WALK. It remains this way until reactivated by another pedestrian. While different in appearance to the driver, to the pedestrian this signal works the same as a typical pedestrian activated signal. Figure 1.3 below shows the actual phases of the PHB for the pedestrian and motorist. This figure illustrates the PHB signal timing scheme for the beacon installed in Fargo. The actual timing scheme varies from beacon to beacon based on crosswalk geometry however the general allocation of time for each phase will be similar at every location.

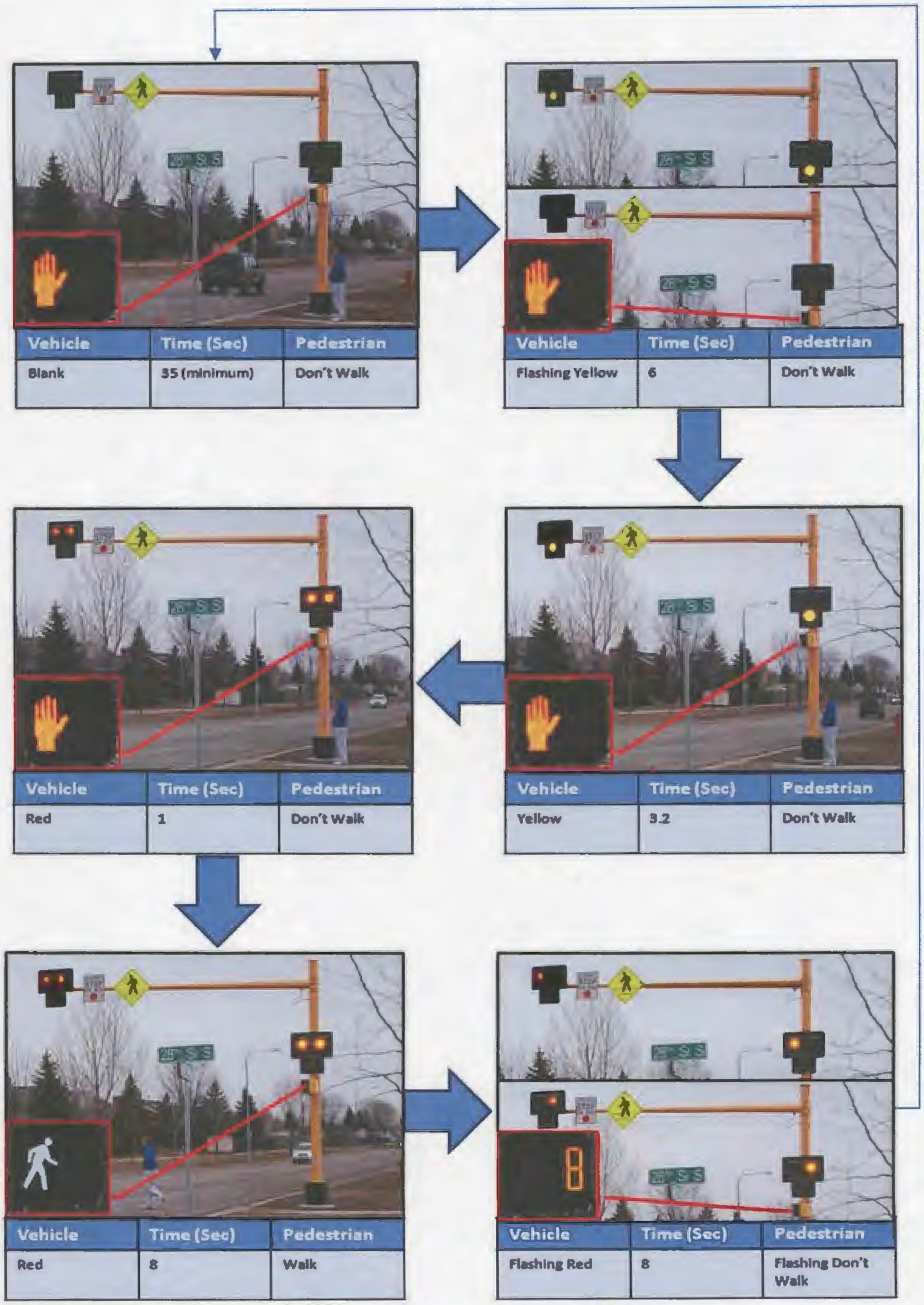


Figure 1.3. PHB Operational Scheme.

1.4. Problem Statement

The large percentage of midblock vehicle-pedestrian crashes involving pedestrians aged 14 or below requires engineers to utilize appropriate positive traffic control devices more frequently, especially within school zones. The most common methods to resolve this problem is the installation of marked or signalized midblock pedestrian crossings. When designing midblock pedestrian crossings the essential objective an engineer should try to achieve is effectively balancing the dual objectives of maximizing pedestrian safety and enhancing motorist convenience. Pedestrian safety can be maximized by optimizing motorist compliance and minimizing pedestrian delay, whereas motorist convenience can be enhanced by minimizing delay to vehicular movements.

The 2000 Highway Capacity Manual (HCM) documented the connection between pedestrian safety and pedestrian delay through level of service (LOS) Tables for pedestrian delay at signalized and unsignalized intersections (see Table 1.2 and 1.3). At unsignalized intersections, the HCM determined that the longer a pedestrian waited for a gap in traffic, the more likely they were to accept shorter gaps as being adequate. This tendency was characterized as “risk taking behavior” because the shorter the gap was, the more dangerous the crossing maneuver became (TRB, 2000). At signalized intersections pedestrians are required to wait for the pedestrian signal to display WALK to allow them access to the crosswalk. The HCM indicates that the longer a pedestrian waited at signal, the more likely they would be to disregard the signal indications and cross without protection. As outlined by the HCM, minimizing pedestrian delay is critical in maximizing pedestrian safety. According to National Highway Traffic Safety Administration (NHTSA) data, about one-third of pedestrian deaths result from disobeying traffic signals or using poor judgment at crosswalks (Copeland, 2008).

Table 1.2. LOS Criteria for Pedestrian Delay at Unsignalized Intersections.

LOS	Average Delay/Pedestrian(s)	Likelihood of Risk-Taking Behavior
A	<5	Low
B	≥5-10	
C	>10-20	Moderate
D	>20-30	
E	>30-45	High
F	>45	Very High

Source: TRB, 2000

Table 1.3. LOS Criteria for Pedestrian Delay at Signalized Intersections.

LOS	Average Delay/Pedestrian(s)	Likelihood of Noncompliance
A	<10	Low
B	≥10-20	
C	>20-30	Moderate
D	>30-40	
E	>40-60	High
F	>60	Very High

Source: TRB, 2000

Although pedestrian delay is important in improving pedestrian safety, motorist compliance should be the number one priority when considering safety. Recently, motorist noncompliance has become increasingly problematic. The use of standard marked crosswalks with only signs and stripes are becoming ineffective in controlling motorist compliance (FHWA, 2005[2]). Many drivers fail to stop or yield to pedestrians attempting to cross streets at marked locations even though State laws require them to do so (FHWA, 2004). This problem requires immediate attention as 4,654 pedestrians were killed in traffic crashes in the United States in 2007 (NHTSA, 2007).

Pedestrian signals are one obvious solution to motorist noncompliance at marked crosswalks. They offer a crosswalk control device that is enforceable by law and are a widely used and accepted strategy for increasing pedestrian safety at these locations. One drawback caused by installing pedestrian signals is the amount of motorist delay that result from their use. At pedestrian activated signals, many times a pedestrian will activate the signal then quickly hurry across the crosswalk without using the full crossing time or many times leave early if an adequate gap presents itself. Once the pedestrian has crossed, motorists are still faced with several seconds of a solid red time and by law must remain stopped. A substantial amount of unnecessary delay can occur on a busy street with a queue of vehicles waiting after a pedestrian has crossed.

When designing a pedestrian crossing there is a continuing challenge in meeting the dual objectives of pedestrian safety and motorist convenience. In the past, engineers have generally installed only street markings and signs at crosswalks if their main priority was to maximize motorist convenience, whereas at locations where pedestrian safety was in question, engineers would install pedestrian signals. The problem with this philosophy is that marked crosswalks with signs may increase motorist convenience but greatly decrease pedestrian safety; while pedestrian signals greatly improve pedestrian safety, but have adverse effects on motorist delay. Maximizing pedestrian safety should always be paramount at school crossings. Understanding, however, the fact that school times are directly associated with morning peak traffic hours coupled with the fact that school zones already have reduced speeds can result in substantial motorist delay and queuing when pedestrian signals are installed. Reducing motorist delay while maintaining pedestrian safety would be a tremendous step forward in the area of crosswalk design. Until standardized treatments are available, this issue requires engineers to become more innovative with their solutions.

The PHB has the potential to solve this problem by achieving better balance between pedestrian safety and motorist delay. The PHB offers a control device that will theoretically demand high levels of motorist compliance through the use of a red signal while reducing the motorist delay by utilizing the alternating portion of the PHB's red phase. This phase allows the driver to begin driving if the pedestrian has passed the crosswalk effectively minimizing unnecessary delay. It is important to note that PHBs will not always have the potential to save the motorist time. Pedestrians may use the entire red phase to traverse the crosswalk eliminating the possibility of an early motorist departure (NCHRP, 2006).

Based on the inherent safety risks present at school zones, Warrant 5 (school zone) incorporates these considerations and is consequently less demanding to achieve than Warrant 4 (pedestrian volume). To effectively ameliorate these safety risks, it is essential to incorporate school zone considerations into MUTCD PHB standards. The current MUTCD PHB standards are newly released and it is unclear whether they can be appropriately applied to school crossings. If the PHB is indeed the best fit for school zones it is essential that their standards are applicable in this context. Research is required to determine if these standards are adequately addressing the delay and safety concerns at school zones and if they are not, address these needs to benefit both engineering design standards and school zone safety as a whole.

1.5. Objectives

Recent implementation and testing of PHBs has been done in Tucson, Arizona and Lawrence, Kansas. However, the use of PHBs within school zones has not been tested. Applicability of PHBs for school zones needs to be analyzed and assessed, along with marked crosswalks and pedestrian signals in determining appropriate school zone crosswalk design and control. School crossings are significantly different than standard crossings, and considering the inexperience of the young pedestrians utilization of these crosswalks, should be handled very carefully. Through this thesis, understanding of pedestrian and vehicle conflict at midblock crosswalks in school zones will be developed and used in improving the state-of-practice. Most notably this research will provide a systematic analysis of the new MUTCD guidelines and standards related to PHB for school crossings.

This thesis has two objectives:

(a) To analyze the applicability of MUTCD PHB standards and guidelines for school zones; and

(b) To develop a systematic framework for determining the most effective crosswalk control device for maximizing pedestrian safety and motorist convenience at school crossings. This framework will be based on the measures of effectiveness of motorist compliance, pedestrian delay, and motorist delay.

1.6. Scope

This research focuses on the transferability of the current PHB guidelines and standards in the most recent update of the MUTCD in December 2009 for school zones in

Fargo, North Dakota. The lessons learned from this analysis will be applicable for and transferable to school zones in small urban areas. In addition, this thesis focuses on evaluation of crosswalk control devices in school zones. All of these crosswalk control devices will be of the midblock context or located at T-intersections, that operate interchangeably to midblock locations. This means that the control devices utilized in this thesis are strictly for controlling motorists for the safety of pedestrians, and not for the sake of opposing traffic. No research wasundertaken on crosswalk scenarios at 4-way intersections, non-school zones, or divided roadways.

Given the great variability of pedestrian and driver behavior, the results of evaluation of devices is subject to a regional and site-specific bias and may not be generalized to other sites. However, the process used to evaluate the devices is applicable to other similar school zones in smaller urban areas. The data collection approach used in this thesis is standard for these scenarios. While the methodology and evaluation approach is universal and thus transferable, the observed data and the related results are not. Any extension or application of this research to other sites, specifically locations outside of the City of Fargo, should therefore include additional data collection and representation.

1.7. Organization of Thesis

This thesis is split up into five chapters. Chapter 1 provides background information, the problem statement, the objectives, and the scope of the research. Chapter 2 presents a literature review of pedestrian studies in general, and PHB related issues and studies in particular. Chapter 3 documents the analysis of MUTCD PHB standards and guidelines, and presents insights into whether they are directly applicable to school zones.

Chapter 4 provides a systematic evaluation framework for crosswalk control devices (including PHB) for school zones and applies this framework to evaluate four distinct school zones in Fargo, North Dakota. Chapter 5 details the significant findings of this research and includes recommendations for future research and application to improve the current state of practice.

CHAPTER 2. LITERATURE REVIEW

In this chapter a review will be conducted regarding issues and studies related to perception of pedestrians' right-of-way at crosswalks, school zones, pedestrian safety with an emphasis on the specified measures of effectiveness (motorist compliance, pedestrian delay, and motorist delay), and the Pedestrian Hybrid Beacon. The studies reviewed in this section only cover relevant topics dealing with the aforementioned crosswalk control devices.

2.2. Perception of Pedestrians' Right of Way at Crosswalks

For any type of crosswalk control device to be effective, pedestrian and motorist competency of the device is required. Pedestrian and motorist competency at crosswalks is related to a clear understanding of right-of-way laws, purpose of crosswalk controls, pedestrian and motorist roles and responsibilities at crosswalks under different controls, and the pedestrian's ability to assess safe gaps for crossing under a variety of situations. Ability to assess safe gaps in traffic was addressed in the problem statement through the use of HCM tables. The purpose of crosswalk controls and user's roles and responsibilities are generally understood at most crosswalk scenarios. Perception of pedestrian right-of-way is the most important factor in pedestrian and motorist competency because it leads to the most frequent occurrence of pedestrian-vehicle conflicts.

Mitman and Ragland (2007) conducted a survey of pedestrians and motorists and found that both groups wrongly perceived the right-of-way for pedestrians at marked and unmarked crosswalks (see Figure 2.1). It is noteworthy that over 35 percent of driver respondents did not believe that pedestrians have the right-of-way even at marked crosswalks. This wrong perception is particularly a concern at midblock locations as over 50% of both pedestrians and drivers incorrectly perceive the pedestrian's right-of-way. This can certainly be a safety concern as it may lead to accident prone conflicts.

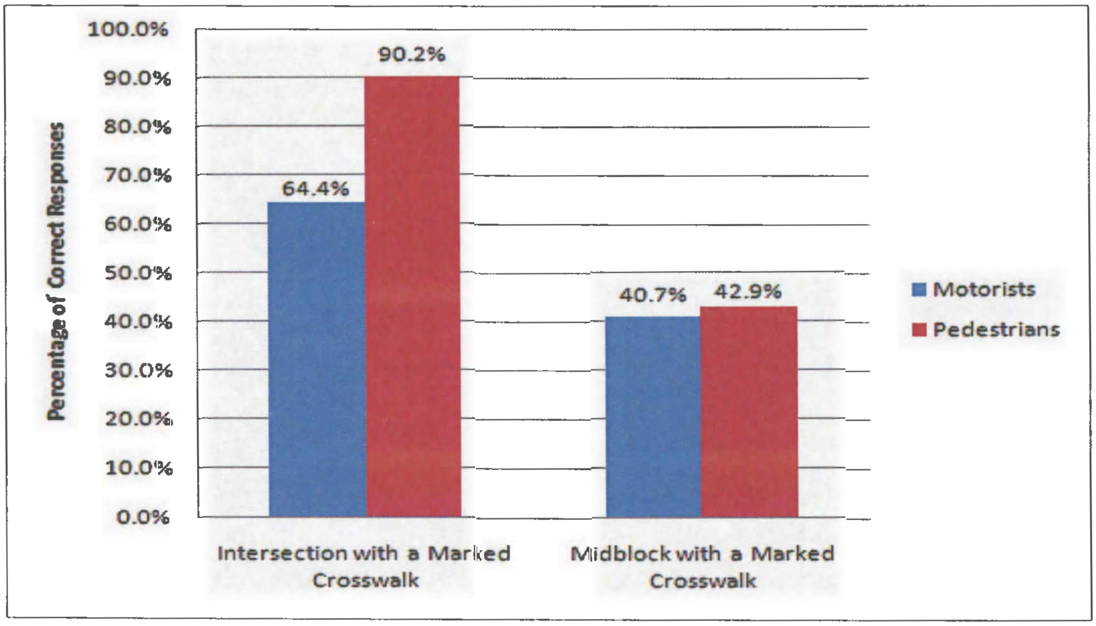


Figure 2.1. Percentage of Correct Responses for Pedestrian Right of Way.
Source: Mitman & Ragland, 2007

Hatfield et al. (2007) conducted a similar study in Australia and investigated pedestrian and driver beliefs and behaviors relating to right-of-way for pedestrians crossing at traffic signals during WALK, flashing DON'T WALK, and DON'T WALK phases, at marked crossings with the pedestrian in the crosswalk and waiting to enter the crossing on the near and far side of the street in relation to the passing vehicle, and at unmarked sections of road under a variety of scenarios. The only scenarios where less than 20% of both pedestrian and driver respondents reported that they would take the right-of-way were when pedestrians crossed on WALK or when a pedestrian is currently traversing the marked crosswalk on the near side of the street. The situation where a pedestrian is waiting to step onto a marked crosswalk and a pedestrian is crossing on the far-side of a marked crosswalk is particularly worrying, because more than 30% of both drivers and pedestrians reported that they would take the right-of-way.

The aforementioned studies were conducted on the general population. It has been demonstrated by Sarkar et al. (2003) that children pedestrians are much less experienced than adult pedestrians and also tend to forget instructions. Sarkar et. All (2003) selected children from two elementary schools in San Diego, California. The secected children (ages 5 to 12 years old) were asked traffic safety questions after looking at photographs of unusual traffic situations and conditions. The study found that children may be overwhelmed by traffic complexity. The percentage of correct responses ranged from less than 30% to the highest at about 50%. Additionally, 90% of the students forgot even the most basic instructions they had learned about assessing traffic conditions (i.e. checking for traffic when crossing the street).

Sarkar et al. (2003) recommended that pedestrian safety education for children needs to offer more individualized and practical training to help children respond to various hazards they are exposed to daily. This study also recommended that more research is necessary pertaining to schoolchildren in urban areas where traffic patterns have become more complex and accommodations for children walking to school have not been modified. In this regard, Foot et al. (2006) conducted a study to find out if children can be sensitized through training to better assess drivers' likely actions. This study found that children's ability to accurately predict drivers' intentions improved with age between 7 and 11 years and training to be more aware of drivers' options when signaling a maneuver improved their accuracy in predicting drivers' intentions. This training effectively allowed the children to better assess crossing scenarios.

In summary, the wrong perceptions of pedestrians' right-of-way may result in behaviors which may increase pedestrian delay and motorist delay. Additionally, these misconceptions can lead to inadvertent noncompliance and unsafe situations. These concerns can be exacerbated within school zones due to lack of experience and training of children. Hence, pedestrian crossing types should be rationalized, and education should be provided regarding rules and responsibilities at and about available crossings in different formats in communities. These improvements can increase awareness, impose appropriate behaviors, and improve overall behavior by both pedestrians and motorists at crossings.

2.3. School Zone Research

Before delving into the specific measures of effectiveness it is essential to build an understanding for the crosswalk context being studied. Isebrands & Hallmark (2007) performed a study that quantified common school zone problems and indentified best practices for elementary and middle schools in Iowa. This study identified several school zone related problems including two dealing with crosswalk activity. These two safety problems were traffic violations such as noncompliant drivers and students ignoring designated marked crossing areas and crossing at unmarked locations.

Recently, the safe routes to school (SRTS) programs have become very influential in the push for increased pedestrian safety at school zones. The SRTS programs are sustained efforts by parents, schools, community leaders, and local, state, and federal governments to improve the health and well-being of children by enabling and encouraging them to walk or bicycle to school. SRTS recommends that for the development of safe and accessible crossings for children is guided by several principles including the need to; establish or identify good crossing locations, reduce crossing distances, provide crossings that are direct, so that children with visual impairments can easily negotiate them, use appropriate traffic controls such as marked crosswalks, traffic signals and warning signs or flashers, and slow motor vehicle speeds (SRTS, 2009).

Dumbaugh & Frank (2007) conducted a review and summary of what is known about the substantive safety effects of the specific countermeasures that comprise SRTS, as well as to identify what was not known. The review focused exclusively on empirical research that examines how the specific countermeasures that comprise SRTS programs affect the rates of vehicle-pedestrian crashes involving children, as well as on empirical studies that examine how these countermeasures may affect changes in pedestrian and motorist behaviors that are known to produce pedestrian crashes.

This study was conducted on 11 of the most typical school zone countermeasures including marked crosswalks, signalized crosswalks, child pedestrian education programs, and motorist education programs. Despite the potential benefits that many of the countermeasures are perceived to have, this study concluded that these benefits are largely presumed rather than known. Two cases in particular (motorist education programs and marked crosswalks at unsignalized locations) were found to have no effect, or even a negative effect, on pedestrian safety. None of the strategies that were studied have been evaluated for their specific effects on the incidence of crashes involving child pedestrians. Given the differences in road knowledge and behavior among adults and children, it is possible that strategies that enhance safety at the aggregate level may have little or no effect on the incidence of crashes involving specific sub-populations, such as children. This study concluded that substantive research focusing specifically on the incidence of crashes involving child pedestrians is needed.

2.4. Pedestrian Safety

Safety should be considered paramount in crosswalk design, particularly in school zones. Baltes & Chu (2002) conducted a study to determine what variables are correlated with pedestrians' perceived crossing difficulty at midblock crosswalks. For this project, crossing difficulty was defined as the risk of being hit by a vehicle, the amount of time to wait for a suitable gap in traffic, presence of a median or other refuge, parked cars, lack of an acceptable traffic gap, or anything else that may affect crossing safety. Results showed that the levels of crossing difficulty improved the greatest when a pedestrian signal was present.

Baltes & Chu (2002) provided evidence that pedestrian signals provide safety advantages compared to standard crossing locations with markings and signs. Furthermore, the Federal Highway Administration (FHWA), (2005) conducted a study to determine whether marked crosswalks at uncontrolled locations were safer than unmarked crosswalks under various traffic and roadway conditions. The results of the study indicate that there were no significant differences in crash rates between marked and unmarked crosswalks on medium to low traffic volumes roadways. More importantly, marked crosswalks were actually associated with higher pedestrian crash rates than unmarked crosswalks on roads with high daily traffic volume. The increase in crash rates at marked crosswalks may be credited to the increased perception of safety that a pedestrian feels at a marked crosswalk. This is a false sense of security due to the low levels of motorist competency, in particular, understanding of right-of-way rules and regulations at marked crosswalks.

2.4.1. Motorist Compliance

Misconceptions of right-of-way at crosswalk locations can lead to noncompliance. In terms of safety at crosswalks, motorist compliance is the single most important consideration when deciding upon a traffic control device. In 2006, the National Cooperative Highway Research Program (NCHRP) developed a report (Report 562) researching ways of improving pedestrian safety at unsignalized crossings. The main consideration of this report was motorist compliance. Comprehensive evaluation data were collected at 40 sites spread across 7 different states and video for an additional two sites was provided to the research team for analysis. The sites were selected to represent various treatment types and site conditions including four midblock crosswalks, five HAWK signal beacons, and three marked crosswalks.

The research team found that the compliancy rate of both the midblock signal and HAWK Signal Beacon scored an average of 95% compliancy rate or greater. This study also found that the compliancy rate at marked crosswalks was strictly dependent on vehicle speed at the crossing location. At locations of 35 mph, the compliancy rate was at best 20%. When signs and markings were installed at locations of 25 mph, the rate was 61% for staged pedestrian crossings and 91% when typical field data was collected. The results of this study can be seen on Table 2.1 below.

Table 2.1. Motorist Compliance at Varying Traffic Control Devices

Motorist Compliance Parameters		Crosswalk Control Method			
		Midblock Signal	HAWK Signal Beacon	Sign and Markings (35 mph)	Signs and Markings (25 mph)
Staged Pedestrian	# of Sites	2	5	2	1
	Average	99	97	17%	61%
Observed Field Pedestrian	# of Sites	4	5	2	1
	Average	95%	99%	20%	91%

Source: NCHRP, 2006

2.4.2. Pedestrian Delay

Pedestrian delay is essential in determining the level safety at a crosswalk due to its direct correlation with risk taking behavior at unsignalized intersections and pedestrian noncompliance at signalized intersections. Confirming the results found in the HCM, Houten et al. (2007) conducted an experiment with the purpose of determining how pedestrian delay affects pedestrian compliance. The study was conducted at two midblock crosswalks in Miami, Florida. At both crosswalks minimum green time was varied between 30 seconds, 60 seconds and 120 seconds. Long minimum green times are associated with longer pedestrian delay. The results of this study show that pedestrian signal compliance at midblock signals is inversely related to minimum green time. One way to improve compliance is to decrease pedestrian delay by reducing minimum green time. For situations when traffic is saturated, minimum green time can be decreased with little effect on motorist delay. Houten et al. (2007) recommends that engineers consider using a 1 minute or 30 seconds minimum green time in isolation mode to prevent pedestrian noncompliance.

2.4.3. Motorist Delay

School zones have increased motorist delay due to reduced speed requirements. Determining the adverse effects that motorist delay has on motorist compliance is essential in determining the amount of pedestrian safety required at a school zone location. Harrell & Bereska (1992) conducted a study to test motorists' compliance patterns after having been faced with previous delay. The participants were 190 motorists southbound on a busy four-lane street in Seattle, Washington followed by a marked pedestrian crosswalk. The study found that the longer the delay upstream of the marked crosswalk on the busy arterial, the less likely the motorist was to comply with pedestrian's right-of-way at the marked crosswalk. This study is significant because it demonstrates possible safety benefits of reducing motorist delay.

2.5. PHB Related Studies

Pedestrian signals and crosswalk markings have been in existence for decades and have been researched significantly in the areas of pedestrian safety and motorist convenience. In contrast, the Pedestrian Hybrid Beacon has limited use and testing but the research available on this crosswalk control device will be addressed in this section.

Fitzpatrick & Park (2009) conducted a study that evaluated the safety effectiveness of the PHB by reviewing crash data before and after PHBs were installed in Tucson Arizona. The study considered 21 intersections at which a PHB had been installed along with a reference group of 102 unsignalized intersections. The evaluation found 13% to 29% reduction in all crashes and approximately 50% reduction in pedestrian crashes after the PHB was installed.

PHBs are also effective safety countermeasures at improving motorist compliance, as documented by NCHRP Report 562. Similarly, Tucson DOT found improvements in motorist compliance with the use of PHBs. The Tucson DOT conducted a before and after study and found that the average percentage of compliant motorists rose from 31 percent at locations before PHB installation to 93 percent at the same locations after the PHB was installed (PBIC, 2002).

Godhavarthy and Russell (2009) documented the effectiveness of the PHB at decreasing unnecessary delay to drivers. Unnecessary delay was defined as the time for which vehicles are stopped at a signalized midblock crossing when pedestrians have cleared the crosswalk but drivers need to remain stopped for a solid red ball according to law. A statistical significant change in unnecessary delays was found by using a PHB at midblock locations instead of standard pedestrian signals. The study has shown that the percentage of pedestrian clearance time, seen as unnecessary delay, is reduced 4.3% for the PHB when compared to a signalized midblock crossing.

2.6. Summary

This chapter presented a general review of literature related to perception at crosswalks, school zone research, and pedestrian safety. In addition, specific issues related to PHB and other devices of control at crosswalks were discussed. In summary, evaluations of crosswalk control and design methods need to include both pedestrian safety and motorist convenience. Pedestrian safety is influenced by compliance of both pedestrians and motorists. Delay experienced by pedestrians and motorists may influence the compliance rate.

To achieve maximum levels of compliance and in-turn safety, pedestrian and motorist competency is required. To achieve acceptable levels of competency, specific schooling techniques are advised on young children who are vulnerable to pedestrian-vehicle conflicts due to their limited road knowledge and traffic assessment capabilities. Over-designing areas where child pedestrians cross the most is one way to protect this age group. Unfortunately, the analysis of newly established standards for PHB in the MUTCD has not been carried out. This analysis is required to establish if these standards are applicable at the school zone context.

Overall evaluation of crosswalk control devices requires school zone specific research. The current practice of applying research conducted at locations outside of school zones using the general population is ignoring specific safety requirements and considerations necessary for young pedestrians. A systematic evaluation framework for identifying the appropriate crosswalk control and design method taking into account both pedestrian safety and motorist convenience will remedy this current gap in research.

CHAPTER 3. ANALYSIS OF MUTCD STANDARDS

The purpose of this chapter is to analyze MUTCD Warrant 5 and PHB standards by performing engineering studies using traffic conditions, pedestrian characteristics, and physical characteristics on the chosen study locations. The engineering study determines if each location satisfies Warrant 5 and justifies the installation of a traffic control signal and/or meets PHB standards to justify use of the PHB. As mentioned earlier, it is not clear if the recently approved PHB standards in the MUTCD are transferrable to school zones. The intent of Chapter 3 is to explore the appropriateness and transferability of the PHB standard to school zones.

3.2. Methodology

Four study sites were selected for analysis based on MUTCD Warrant 5 and PHB standards. Warrant 5 is a pedestrian signal warrant derived specifically for use in school zones, whereas the current PHB standards do not specify their intended context or the limits of their standards for particular locations. The methodology for Chapter 3 will be a comparative analysis between Warrant 5 and PHB standards. Based on Warrant 5's extensive history of acceptance, it will be used as the control for the analysis.

Based on how transferable the results of the PHB standards are compared to Warrant 5 results, conclusions can be drawn about the adequacy of the PHB standards in the school zone context:

1. If Warrant 5 and PHB standards are both met, then it can be concluded that current PHB standards adequately address school zone requirements.

2. If Warrant 5 is met and PHB standards are not met, it can be concluded that current PHB standards do not adequately address school zone requirements.
3. If Warrant 5 is not met and PHB standards are met, it can be concluded that current PHB standards are far too light for application at standard locations.

To determine if a traffic control signal should be considered based on Warrant 5 standards it is required to compare the frequency and adequacy of gaps in the vehicular traffic stream. This number is then related to the number of school children crossing the major street. This major street must be located at or near an established school. If the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period then a traffic control signal is warranted. If the number of adequate gaps in the traffic stream in this time period is more than the number of minutes then a traffic control signal is not warranted. Also, a minimum number of 20 pedestrians per hour during the peak hour are required at the test site for Warrant 5 to be met (FHWA, 2009). Due to the pedestrian per hour requirement, typical testing periods for Warrant 5 is 60 minutes. This means that the site must have fewer than 60 gaps per hour to meet Warrant 5 and justify installation of a pedestrian signal.

PHB standards are met in a much different way. Pedestrian hybrid beacons standards are based on vehicle volume counts and crosswalk width measurement as opposed to gap studies. The vehicle volume count number and crosswalk width are input into either Figure 3.1 or 3.2, based on roadway speed, and a corresponding number of pedestrians is output from the Figure. This output value is the minimum number of pedestrians during the peak hour required to warrant PHB installation. If the location has equal to or more than the required number of pedestrians per hour shown by the Figures, the signal is eligible for installation. Similar to Warrant 5 requirements, a minimum threshold value of 20 pedestrians per hour must be present during the peak hour for PHB installation (FHWA, 2009).

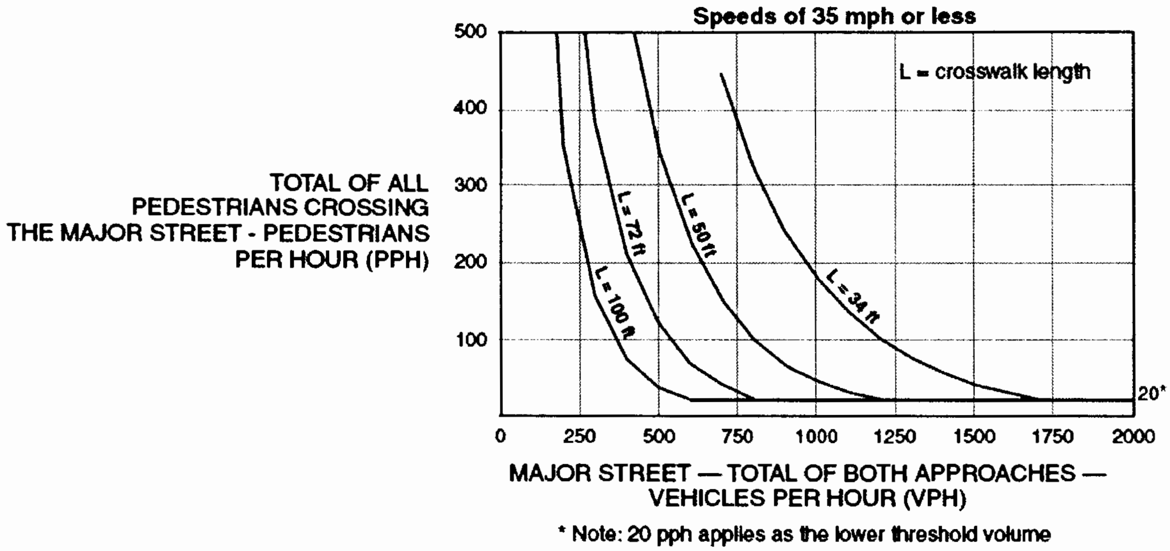


Figure 3.1. Guidelines for the Installation of PHB on Low-Speed Roadways.
Source: FHWA, 2009

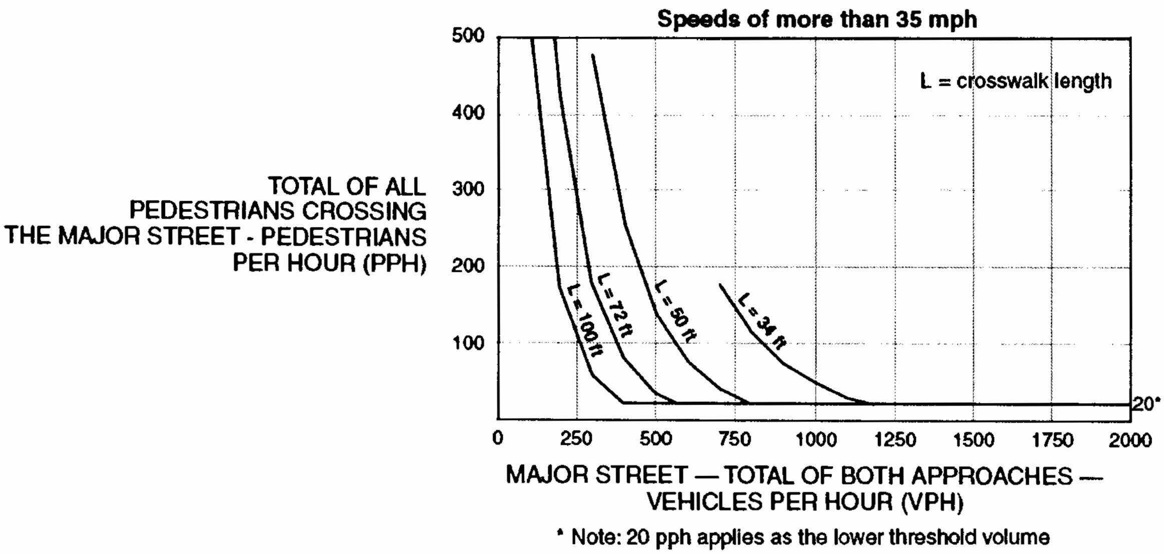


Figure 3.2. Guidelines for the Installation of PHB on High-Speed Roadways.
Source: FHWA, 2009

Figure 3.3 shows the methodology used for analyzing MUTCD's Warrant 5 and PHB standards. First, study sites are chosen. Second, data pertaining to pedestrian volume, vehicle volume, and gap data are collected for the chosen sites. Third, applicability and satisfaction of MUTCD's Warrant 5 and PHB standards are determined using the collected data. Finally, recommendations to remedy inadequacies of PHB standards for school crossings will be provided if needed. Reasons for inadequacies and recommendations for applicability of standards will also be explored and identified.

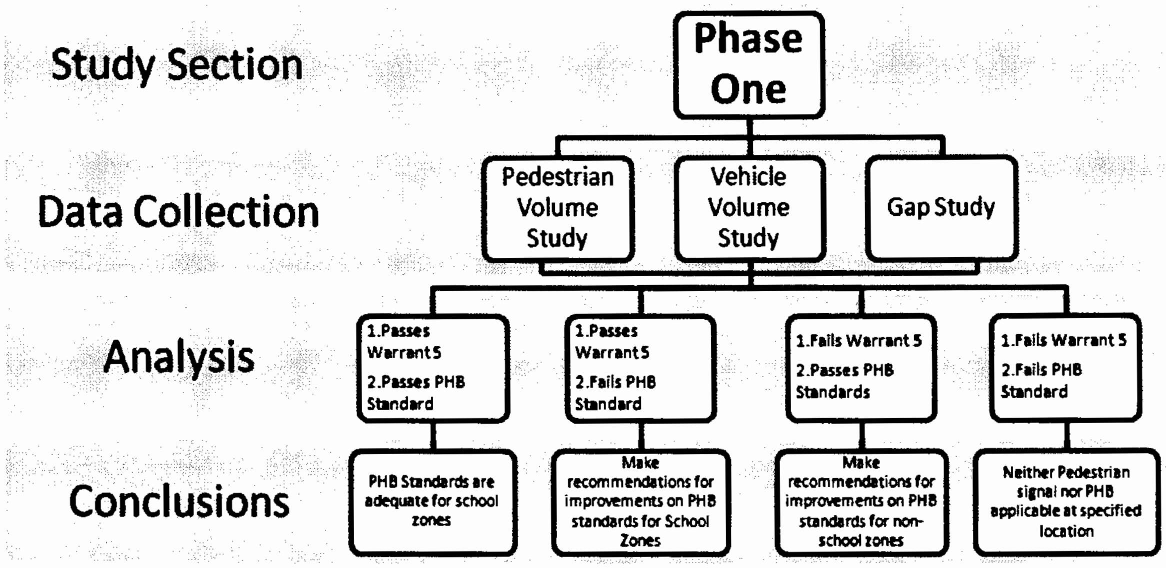


Figure 3.3. Methodology for Analyzing MUTCD PHB Standards.

3.3. Description of Study Sites

Four different school crossings were examined for applicability and satisfaction of MUTCD's Warrant 5 and PHB standards. The criteria for selected study sites in this Chapter considered three separate characteristics. First, each crossing had to be located within a school zone. Second, each crossing had to be configured as a midblock or operate as a midblock. For example, if the crossing were located at another location such as a T-intersection the signal must be strictly intended for pedestrian control without any consideration to opposing traffic. Finally, sites were selected with varying crosswalk geometries and traffic volume at each study site to test the PHB standards under a multitude of scenarios.

The first school crossing was located on the T-intersection of 28th Street and 40th Avenue South adjacent to Centennial Elementary School (see Figure 3.4). At the time of data collection this site had two marked crosswalks with corresponding pedestrian signs on both sides of 28th Street on 40th Avenue. Later this site was reconstructed and the first PHB in the city of Fargo was installed alongside the east crosswalk, while the west marked crosswalk and pedestrian sign were removed. This site was selected for PHB installation due to numerous complaints from parents about the unsafe nature of the crosswalk.

Picture on the left is of the study site and is shot looking from the Northwest. Picture on the right is an aerial view of the T-intersection of 28th Street and 40th Avenue South.

Figure 3.4. Centennial Elementary School Study Site.
Source (Aerial Photograph): Microsoft, 2010

The second test site was located on the T-intersection of 16th Street and 13th Avenue South directly outside of Carl Ben Eielson Middle School (see Figure 3.5). This location was selected for installation of a PHB due to the high volume of traffic on 13th Avenue South. At the time of data collection the crossing location was completely uncontrolled, meaning it did not have any markings, signs, or signalization. Due to the unsafe nature of an unmarked crosswalk located on a high volume roadway such as this, a large percentage of pedestrians crossed at 17th Street. This crosswalk is only a half block west of the test site and has a traffic control signal installed there. The current signal located on 17th Street allocates most of its green time to 13th avenue. As a result, the pedestrian delay at this signal is significant. If a PHB were installed at 16th street, these pedestrians could potentially migrate to the newer control device constructed specifically for their convenience and safety. As a result, the pedestrian volume count for this location included all of the people that crossed at 16th Street as well as each pedestrian who crossed at 17th Street.

Picture on the left is of the study site and is shot looking from the Northeast. Picture on the right is an aerial view of the T-intersection of 16th Street and 13th Avenue South.

Figure 3.5. Carl Ben Middle School Study Site.
Source (Aerial Photograph): Microsoft, 2010

The third study site already had a pedestrian midblock signal installed. Installation of a signal indicates that this location has passed MUTCD Warrant 5 standards at some point in the past. This signalized crosswalk is located outside of Horace Mann Elementary School on 2nd Street between 10th and 11th Avenue North (see Figure 3.6).

Picture on the left is of the study site and is shot looking from the Southwest. Picture on the right is an aerial view of the midblock crosswalk located on 2nd Street North.

Figure 3.6. Horace Mann Elementary School Study Site.
Source (Aerial Photograph): Microsoft, 2010

The final study site was located adjacent to Roosevelt Elementary School. Roosevelt Elementary School currently resides on 10th street between 10th and 11th avenue North (see Figure 3.7). Similar to Horace Mann, this site has already satisfied MUTCD Warrant 5 standards and has a midblock pedestrian signal installed.

The fact that Roosevelt and Horace Mann have previously met warrants to install a pedestrian signal alleviates the need to conduct Warrant 5 testing on these locations. Additionally, it is impossible to perform a gap study at locations where traffic control signals are present due to the artificial gaps that a pedestrian signal creates. These artificial gaps are created when the pedestrian signal is active and there is no vehicle movement at the crosswalk being studied. These gaps would create study results that are unrepresentative of the actual crossing environment if a signal was not present. One option would be to turn off the pedestrian signal to perform a gap study on this location during the morning and afternoon peak periods when the signal is utilized the most. The drawback of turning off the signal is that if it is indeed warranted, this action will jeopardize the safety of the young pedestrians who utilize this signal on their commute to and from school. As a result, Warrant 5 analysis will be conducted only at Centennial and Carl Ben Eielson study sites. It will be assumed that Roosevelt and Horace Mann already meet current standards unless the pedestrian and vehicle volume data collected for PHB standards analysis provokes us to believe otherwise. Although only two of the locations were analyzed for Warrant 5 standards, they were all analyzed for PHB standards.

Picture on the left is of the test site and is shot looking from the Southwest .Picture on the right is an aerial view of the midblock crosswalk located on 10nd Street North

Figure 3.7. Roosevelt Elementary School Study Site.
Source (Aerial Photograph): Microsoft, 2010

There were two study periods for each crosswalk, one in the morning (AM) and one in the afternoon (PM). The AM study period would start 45 minutes before school started and end 15 minutes after school started. The PM study period would start 15 minutes before school ended and conclude 45 minutes after school ended. Every school crossing was located in a 20 mph school zone, which was in effect during the entirety of the analysis period. Each pedestrian related study was conducted on days with no precipitation with temperatures ranging from 60-75°F for the morning period and 70-85°F for the afternoon period to promote pedestrian activity. Geometries, street configurations, and traffic volumes for each crosswalk is shown in Table 3.1. The AADT referenced in this Table stands for Annual Average Daily Traffic. AADT is the total volume of vehicle traffic on a road for a year divided by 365 days. AADT is a useful and simple measurement of how widely a road is traveled and is used for roadway classification. AADT and the road classification data were obtained from the Fargo Moorhead Metro Council of Governments' (COG) traffic counts taken in 2005-2006. AADT and other characteristics shown in Table 3.1 provide a useful guide in determining the similarities and differences of each crosswalk.

Table 3.1. Study Site Description and Characteristics.

Parameters	Horace Mann	Roosevelt	Carl Ben Eielson	Centennial
School Duration	8:40-3:02	8:30-2:52	7:50-3:17	8:20-2:42
AM Test Period	7:55-8:55	7:45-8:45	7:05-8:05	7:35-8:35
PM Test Period	2:47-3:47	2:37-3:37	3:02-4:02	2:27-3:27
Width (ft)	30	31	40	40
Configuration	2 Lane, 2 way	2 lane, 1 way	2 lane, 2 way	2 lane, 2 way
Speed Limit (mph)	25	30	25	30
Road Classification	Minor Arterial	Principal Arterial	Minor Arterial	Minor Arterial
AADT N or W	4850 N	10600 N	15700 W	7000 W
AADT S or E	5700 S	11000 S	13000 E	5800 E

Source (AADT and Road Classification): FM Metro COG, 2006

3.4. Data Collection

In this section, specific types of data collected to satisfy MUTCD Warrant 5 and PHB standards requirements are documented. Additionally, the corresponding methods used to collect the data also discussed. Data on pedestrian volume, traffic volume, and traffic gaps were collected.

3.4.1. Pedestrian Volume Study

Pedestrian volume studies are obtained by recording the number of pedestrians passing a point, entering an intersection, or using a particular facility such as a crosswalk or sidewalk (Robertson, 1994). The pedestrian volume data for this thesis were collected by counting the number of pedestrians utilizing the crosswalk at each study site. As previously mentioned, the Carl Ben Eielson study site additionally counted the pedestrians who chose to cross at the traffic control signal located a half block west of the study site. The pedestrian count was taken manually through direct observation and recorded on a tally sheet.

3.4.2. Traffic Volume Study

Traffic volume studies are conducted to determine the number, pattern of movements, and classifications of roadway vehicles at a given location. This data can help identify critical flow time periods, determine the influence of large vehicles or pedestrians on vehicular traffic flow, or document traffic volume trends (Robertson, 1994). For analysis purposes in this thesis, the only value of interest was the number of vehicles observed during the testing period.

The traffic volume was recorded using the JAMAR Traffic Data Collector (TDC) 12. The TDC-12 is an electronic hand-held device that enables the observer to do some of the most common manual traffic data collection. The TDC-12 is designed to make collection of vehicle movement data easy and accurate. The buttons are arranged according to a typical intersection. There are 16 buttons, with 12 normally used for the left, through, and right movements from each of the four approaches. The additional four buttons are user-defined; they can be used for bicycles, pedestrians, or whatever the user requires (JAMAR Technologies Inc., 2009). The user defined buttons were used to count the number of pedestrian-vehicle conflicts that occurred during the study. Pedestrian-vehicle conflicts are discussed in Chapter 4.

3.4.3. Gap Study

A minimum adequate gap is defined as the time, in seconds, for one or a group of pedestrians to perceive and react to a specific traffic situation and cross the roadway from a point of safety on one side to a point of safety on the other (Robertson, 1994). Gap studies determine the number of adequate gaps in traffic passing a particular location or point (Robertson, 1994). A gap in traffic is a function of crossing distance, walking speed, predominant number of rows in the group, time headway between rows, and the group startup time. Equation 3.1 shows a formula commonly used to calculate the minimum adequate gap in traffic for a particular location (Robertson, 1994). For the context of this thesis, a gap is determined by counting the time that elapses from when the rear of a vehicle passes a point on a roadway until the front of the next arriving vehicle, from either direction, passes the same point.

Groups of pedestrians waiting to cross a roadway will generally arrange themselves in rows one behind the other. Since an adequate gap determines the amount of time it takes the entire group to enter the crossing, it is necessary to determine the predominant number

Minimum Gap Equation

$$G = \left(\frac{W}{S}\right) + [(N - 1) \times H] + R \qquad \text{(Equation 3.1)}$$

G = minimum adequate gap in traffic, seconds
W = crossing distance or width of roadway, feet
S = walking speed, ft/sec
N = predominant number of rows (group size)
H = time headway between rows, seconds
R = pedestrian startup time, seconds
Source: Robertson, 1994

of rows waiting to cross at the time crossing begins (Robertson, 1994). The predominant number of rows will be documented by recording the number of rows for each group on a tally sheet. This study will be performed concurrently with the pedestrian volume study. Each pedestrian group will be recorded on a sheet of paper along with group size and number of rows. The predominant number of rows will be the number of rows for the 85th percentile group size (Robertson, 1994). Time headway between rows and pedestrian startup time are generally assumed to be 2 seconds and 3 seconds respectively (Robertson, 1994). Group size is comprised of row width and number of rows.

Pedestrian walking speed is the speed at which a pedestrian crosses the street. Pedestrian walking speed is an important test parameter in school zone testing. This is because the typical average walking speed for a child generally varies greatly from that of an adult (Robertson, 1994). To determine the pedestrian walking speed, the pedestrian walking time was collected first using a stop watch and a tally sheet. The walking time was taken from the pedestrian's first step off of the sidewalk and onto the street and was concluded when the pedestrian took his or hers' first step across the street and back onto the sidewalk. Another important parameter was street width which was determined using a measuring wheel. The walking speed was subsequently calculated as the length of the road divided by the walking time. According to Robertson (1994), a sample size of 100 observations is generally considered adequate for a walking speed study.

Once crosswalk width, predominant number of rows, and walking speed were determined, these parameters along with the given values for pedestrian startup time and time headway between rows were input into Equation 3.1 output the minimum adequate gap length. Based on the outputted gap length, the JAMAR TDC-12 Traffic Data Collector device was used to determine the number of gaps of this length or longer.

Collecting gap data is a simple process using the TDC-12. The observer firsts puts the gap study cover on the TDC and changes the collection method to gap study on the device. Once the study has begun, the observer presses the Direction 1 GAP key when a gap starts, i.e. the end of a car just passes over the crosswalk in question, and there isn't a car immediately behind it. The observer continues to hold down the button until the front of the next car crosses the crosswalk. The observer simultaneously duplicates this procedure for the opposite direction as well. The TDC-12 actually keeps track of three different gaps, even though only two are measured. One for each of the GAP buttons the observer presses while doing the study and one that is a combination gap that is only valid when both GAP buttons are pressed simultaneously. The JAMAR device separates the gaps into two second groupings starting at 2-3 seconds and progressing upwards until it reaches 29 seconds. Every gap over 29 seconds is grouped together in the final column. Using the numbers the JAMAR device recorded, the observer can total up all of the combined gaps that are larger than the minimum gap size to determine the amount of adequate gaps.

3.5. Results and Discussion

In this section, collected data will be documented and analyzed to determine if the PHB standards are transferrable to the school zone context or if modifications are needed. Modifications and recommendations will also be provided, if needed.

3.5.1. Pedestrian Volume

The results to the pedestrian volume study can be found on Figure 3.8. The most important take away from the pedestrian volume study was found at the Horace Mann study site. At this site, the twenty pedestrians per hour required to warrant a signal under MUTCD Warrant 5 standards was not achieved. There is already a pedestrian signal installed at Horace Mann indicating that at one point this crossing met the required number of pedestrians. This drastic variation is undoubtedly due to a recent change in the range of ages of children who attend Horace Mann.

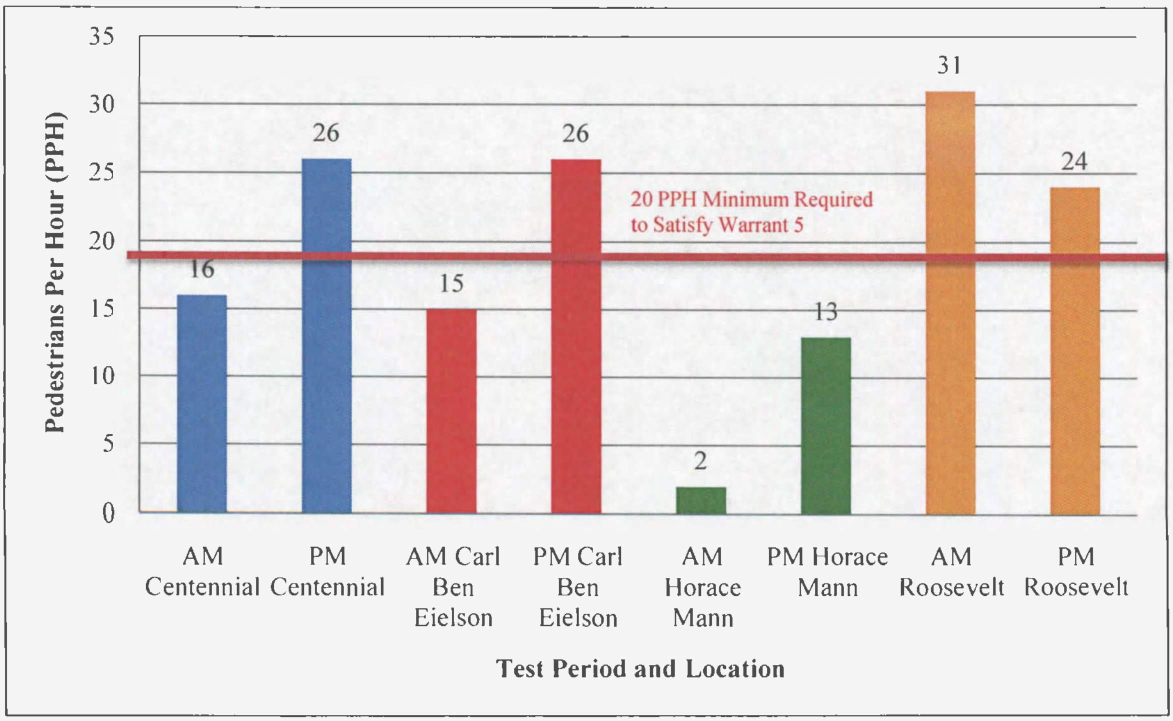


Figure 3.8. Pedestrian Volume.

According to the Horace Mann/Roosevelt Elementary school website, before the fall of 2008 the two schools were full functioning kindergarten through 5th grade elementary schools. In the fall of 2008, Horace Mann and Roosevelt were paired and the grades that each school offered were split. Horace Mann now houses the kindergarten, 1st, and 2nd grades for the previously unpaired schools, whereas Roosevelt maintains the 3rd, 4th, and 5th grades. Kindergarten, 1st, and 2nd graders are generally between the ages of 5 and 8. These students are typically too young and inexperienced to be able to navigate to and from school safely by themselves. This split in grades explains why so few children currently walk to and from school at Horace Mann and why so many walk to and from Roosevelt.

It is important to note that for all cases, except for Roosevelt, more kids walked home from school than walked to school. Such factors as an increase in temperature, lower traffic flow, the availability of the child's parent to drive them to school in the morning as opposed to from school in the afternoon, and possibly just morning grogginess may play a role in this decision. Roosevelt had an increase in the number of pedestrians in the morning due to a fundraiser the school was offering that encouraged children to prepare for an upcoming MS (multiple sclerosis) Benefit Walk. A teacher would take a group of children walking in the neighborhood and utilize the pedestrian signal on their way out and coming back to the school. If these students were not counted in the final AM tally, the volume count would be 17. This would follow the trend that the other three schools displayed.

When the pedestrian volume is broken down into 15-minute intervals there are several trends that quickly become apparent (see Figures 3.9 and 3.10). Intuitively, after school has started and before school ends there is little to no pedestrian activity at the study sites. Also, over 30 minutes before school has started and over 30 minutes after school has ended the pedestrian activity tails off toward zero. As indicated by these graphs, when analyzing school crossings, the critical time periods are the two 15-minute intervals before school has started and the two 15-minute intervals after school has ended. Analyzing pedestrian activity based on per hour volumes, as Warrant 5 and PHB standards require,

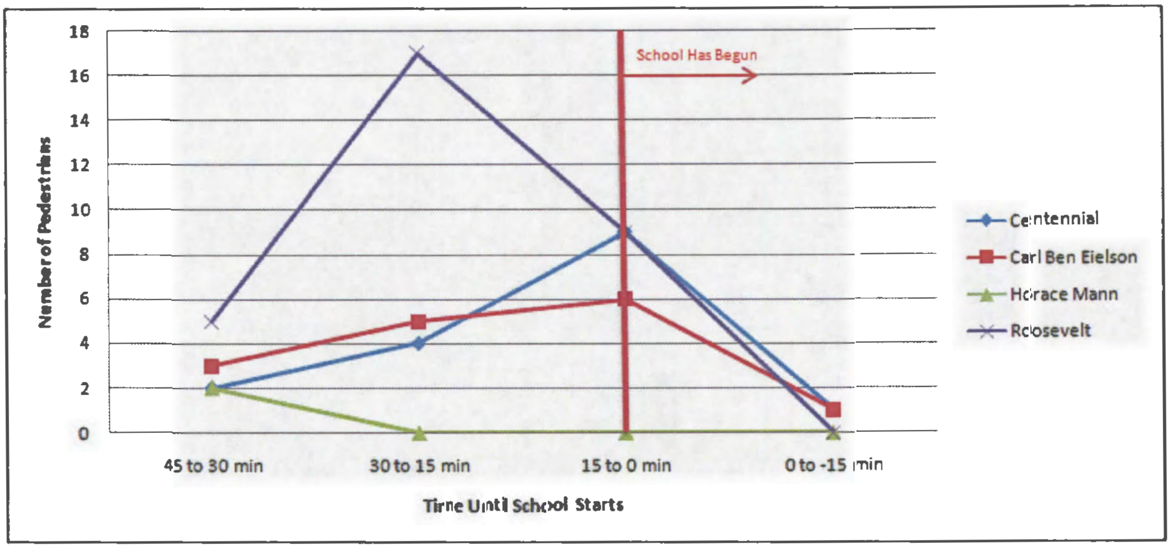


Figure 3.9. AM Pedestrian Volume by 15 Minute Intervals.

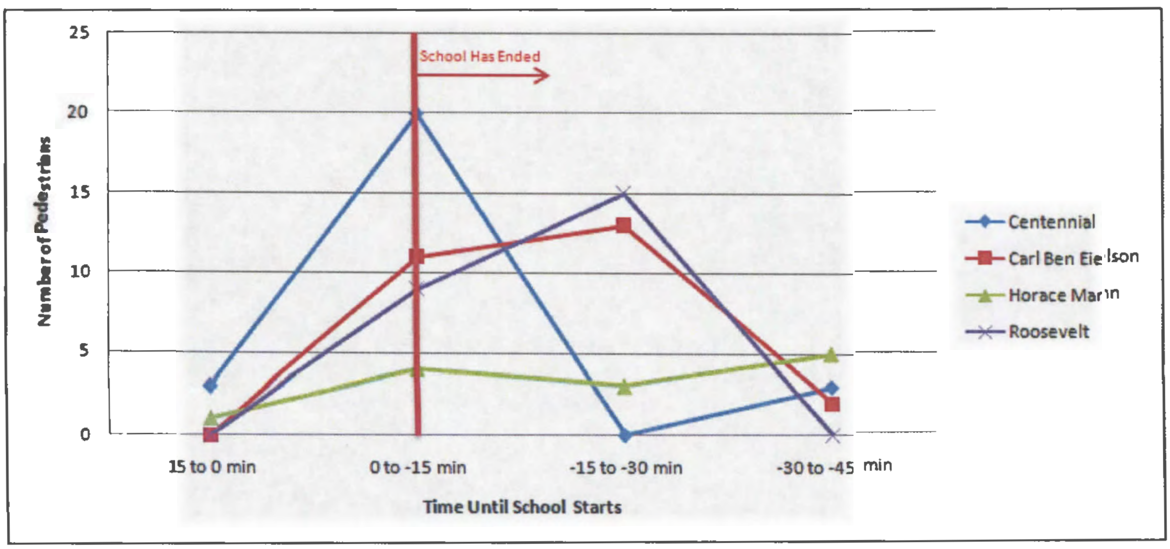


Figure 3.10. PM Pedestrian Volume by 15 Minute Intervals.

appears to be inappropriate for school crossings. Further pedestrian volume data can be found in Appendix B.

3.5.2. Vehicle Volume

Figures 3.11, 3.12, and 3.13 provide summaries of the vehicle volume data that were collected. When analyzing the vehicle volume on a per hour basis there are very few takeaways. The lowest traffic volumes were recorded at Horace Mann. Typically low volumes are associated with high amounts of adequate gaps. As a result, consideration to remove the traffic signal located at this school crossing is recommended to the City of Fargo Engineering Department. Possibly the most dramatic statistic is the increase in traffic volume at the Carl Ben Eielson study site from the AM to the PM. Generally higher vehicle volumes are associated with rush or peak hour time periods. A rush or peak hour is a part of the day during which traffic congestion on roads and crowding on public transport is worst. Normally, this happens twice a day; once in the morning and once in the evening,

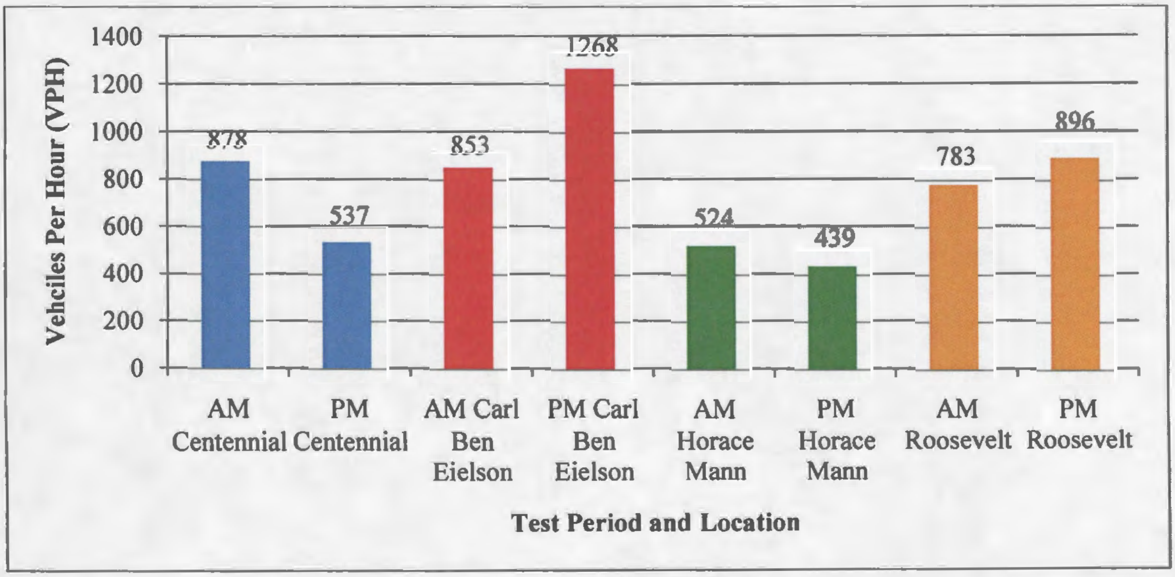


Figure 3.11. Vehicle Volume.

the times during when most people commute (Merriam-Webster's Online Dictionary, 2009). These times are generally around 8 AM and 5 PM. The Carl Ben Eielson traffic counts contradicts this belief with an almost 50% increase from the morning testing period (which included a portion of the AM rush hour) to the afternoon testing period. This major discrepancy can be explained through further examination of the primary use of 13th Avenue South. 13th Avenue South provides access to West Acres Mall as well as an assortment of other retail centers that are popular in the afternoon and are not open during the typical AM rush hour.

After breaking down the vehicular volume into 15 minute intervals, the AM study confirms the rush hour hypothesis that vehicular volume increases around 8 AM. Figure 3.12 displays the interval that includes 8 AM with a star. Every interval with a star and the interval directly preceding it are drastically higher than those before or after. The PM volumes have no rush hours associated with the testing period. This fact was verified with an almost constant vehicular volume during the four testing intervals for all four sites. Based on the vehicular and pedestrian volume results, it is recommended that schools begin classes at least a half hour after or before 8 AM in the morning to decrease the risk that walking to school in peak vehicular volumes pose. Tabular representation of vehicle volume can be found in Appendix C.

3.5.3. Gap Study

The pedestrian volume study resulted in only 42 test subjects for Centennial and 41 for Carl Ben Eielson. According to Robertson (1994), these numbers are insufficient in determining pedestrian walking speed. Furthermore, due to the unsafe environment at the

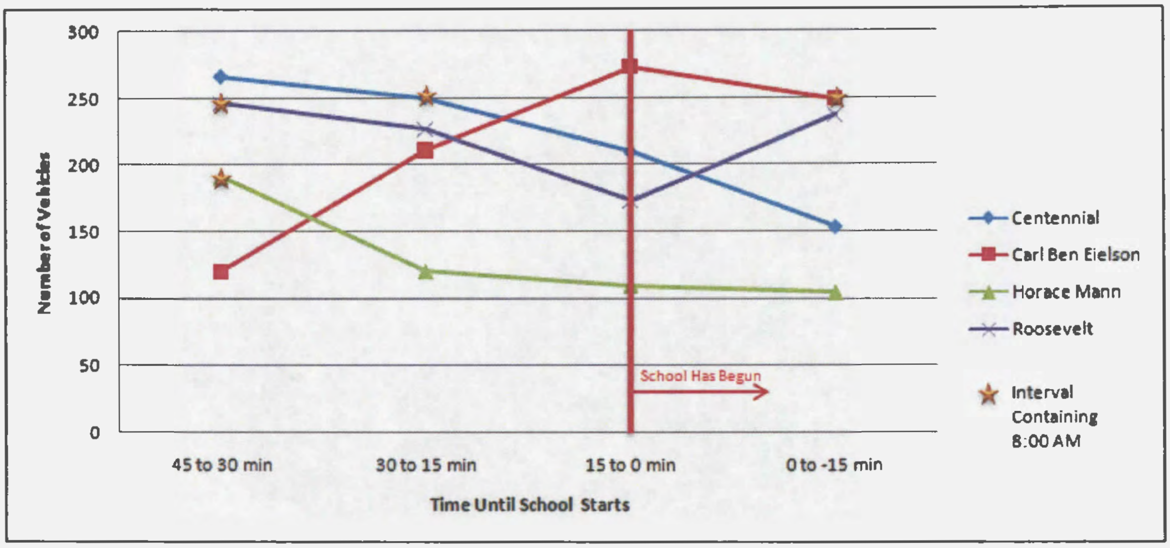


Figure 3.12. AM Vehicle Volume by 15 Minute Intervals.

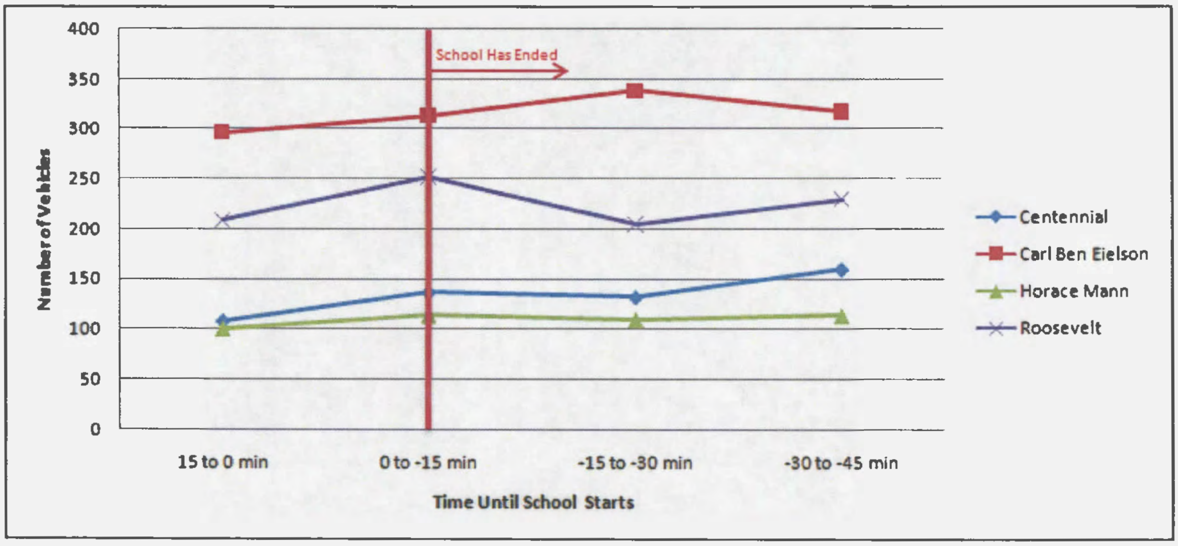


Figure 3.13. PM Vehicle Volume by 15 Minute Intervals.

marked crosswalk at Centennial and unmarked location at Carl Ben Eielson (evidence provided in Chapter 4), pedestrians were forced to rush across the street to avoid conflicts with vehicles. This, coupled with the large percentage of pedestrians riding bicycles to school, resulted in walking speeds more than doubling the MUTCD standard of 3.5 ft/s.

For the sake of pedestrian safety, the MUTCD standard for walking speed of 3.5 ft/s will be used to determine minimum adequate gap time.

The resulting predominant number of rows for Centennial and Carl Ben Eielson study sites was one. 87.5% of the pedestrian groups were alone at Centennial's marked crosswalk. At the Carl Ben Eielson site a large portion of the counted pedestrians utilized the traffic signal located on 17th Street. It is impossible to determine if these pedestrians will indeed utilize the future PHB instead of this traffic signal. Consequently, the number of predominant rows was determined by using only those pedestrians who crossed at the future PHB location. Using this sample population, again just over 85% of these groups were alone.

Using 3.5 ft/s for the walking speed, 1 as the predominant number of rows, 2 seconds for pedestrian startup time, 3 seconds for headway between rows, and 40 ft for the crossing distance for both locations, the minimum adequate gap time was solved using Equation 3.1. The resulting minimum adequate gap was incidentally 15 seconds for both locations when rounded up for the sake of pedestrian safety ($G = (40/3.5) + [(1-1)*(2)] + 3 = 14.43$ seconds).

Although the adequate gap size in this study was 15 seconds, due to the restrictions of the JAMAR TDC, 15 seconds was also grouped together with 14 seconds which was deemed an inadequate gap length. As a result, all adequate gaps were first considered to be those 16 seconds and above first. Following the 16 second adequate gap consideration, a check was performed where all gaps 14 seconds and longer were considered adequate. Fourteen was chosen as the cutoff because using fourteen allowed all of the 15 second gaps to be counted. Adding the 15 second gaps in turn required that all of the 14 second gaps be included as well. Regardless, both testing periods for each of the two minimum adequate gap requirements met Warrant 5 standards to install a pedestrian signal at Centennial and Carl Ben Eielson. The results for the gap test are presented in Figure 3.14. Tabular representation of gap study results can be found in Appendix D.

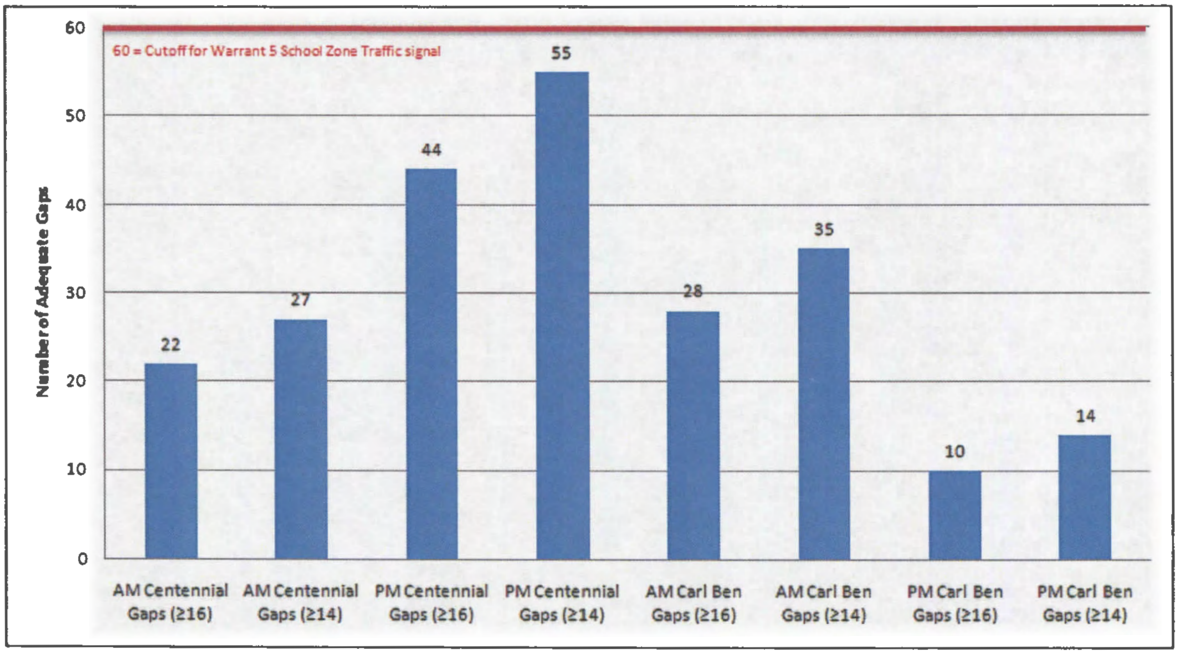


Figure 3.14. Gap Study Results.

3.5.4. Comparative Analysis of Warrant 5 versus PHB Standards

Figures 3.8 and 3.14 reveal that the PM study periods for both Centennial and Carl Ben Eielson satisfy Warrant 5 standards with over 20 pedestrian per hour and lewer gaps than minutes in the study period. The AM study periods on the other hand do not have the required number of pedestrians to satisfy these standards. It is important to note that according to these standards; only one peak pedestrian hour is needed to satisfy the Warrant 5 requirements for a pedestrian signal. Warrant 5 also requires that the school crossing signal not be installed at locations where the distance to the nearest traffic control signal along the major street is less than 300 feet unless the proposed traffic control signal will not restrict the progressive movement of traffic (FHWA, 2009). Centennial and Carl Ben Eielson both are in excess of 300 feet from the nearest traffic control signal.

In addition to these two locations, Roosevelt will also be used to test the adequacy of PHB standards in relation to school zones. Roosevelt is used because it has previously passed MUTCD warrants to install a pedestrian signal and still maintains the adequate amount of pedestrians for both AM and PM testing periods. Contrarily, Horace Mann did not receive the adequate amount of pedestrians to warrant a standard pedestrian signal at either the AM of PM study times. Consequently, this location will not be used to test the PHB standards.

The PHB figures require that a minimum of 20 pedestrians per hour be present during the peak hour. Consequently, the PM Centennial and Carl Ben Eielson test results were utilized once again. Centennial's PM vehicle volume had 601 vehicles and the study site has a crosswalk width of 40 ft. Figure 3.15 below shows the results of the Centennial PM test using the MUTCD PHB figure. The PHB figure requires that almost 500 pedestrians per hour (PPH) be required for a PHB to be installed at the study site. The difference between the PHB required PPH and the observed PPH is approximately 470 PPH, which would require an 1823.1% increase in PPH at the test site during.

The next testing location considered was Carl Ben Eielson. Carl Ben Eielson's PM vehicular volume was 1268 vehicles and the study site has a crosswalk width of 40 ft. Figure 3.16 depicts the results of the Carl Ben Eielson's PM test using the PHB figure. The PHB figure requires that approximately 45 PPH be required for a PHB to be located at the study site. The difference between the PHB required PPH and the observed PPH is approximately 19 PPH, which would require a 73.1% increase in PPH at this test site.

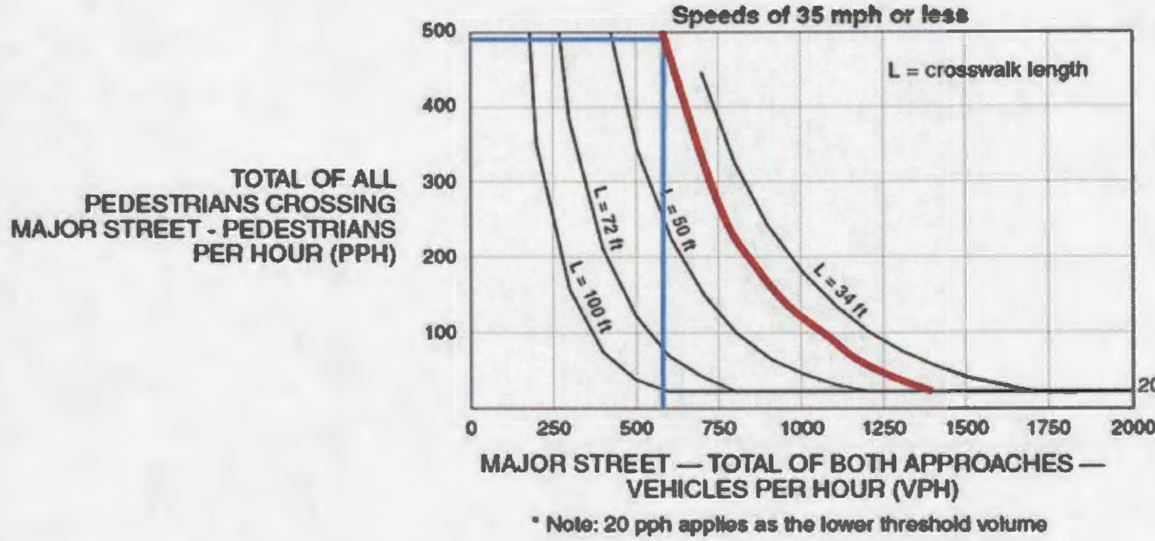


Figure 3.15. PM Centennial PHB Standard Results.

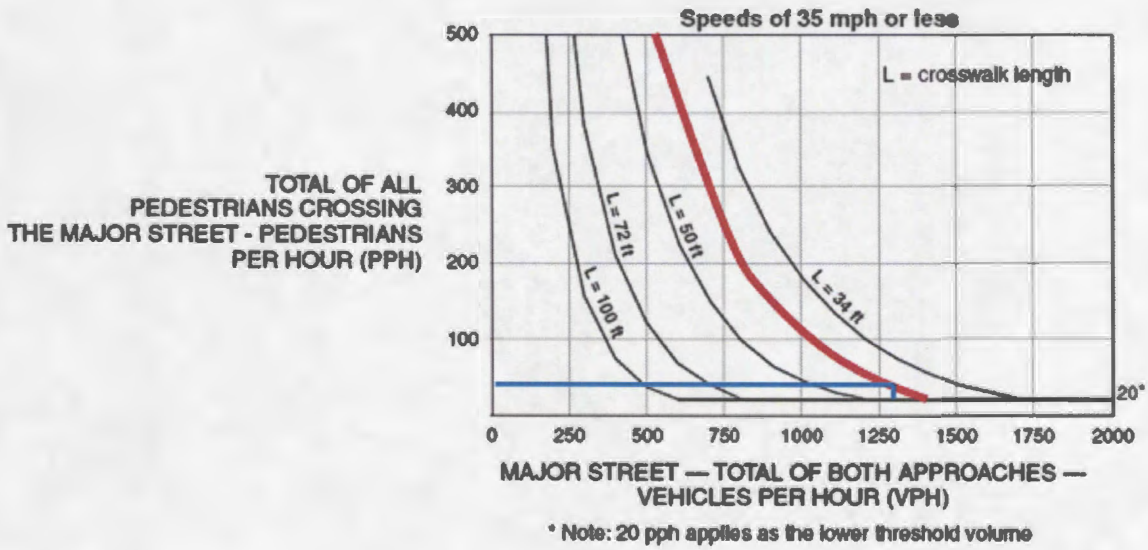


Figure 3.16. PM Carl Ben Eielson PHB Standard Results.

The final test site considered was Roosevelt. Roosevelt's AM and PM pedestrian counts satisfied MUTCD's Warrant 5 standards with 31 and 24 respectively. The corresponding vehicular volumes were 783 vehicles for the AM and 896 vehicles for the PM. Figures 3.17 and 3.18 depict the PHB figure results using the Roosevelt data. The PHB figure requires that approximately 385 PPH and 300 PPH be required for a PHB to be installed at the study site during the AM and PM testing periods. This would require increases of 1141.9% for the AM testing period and 1150.0% for the PM testing period.

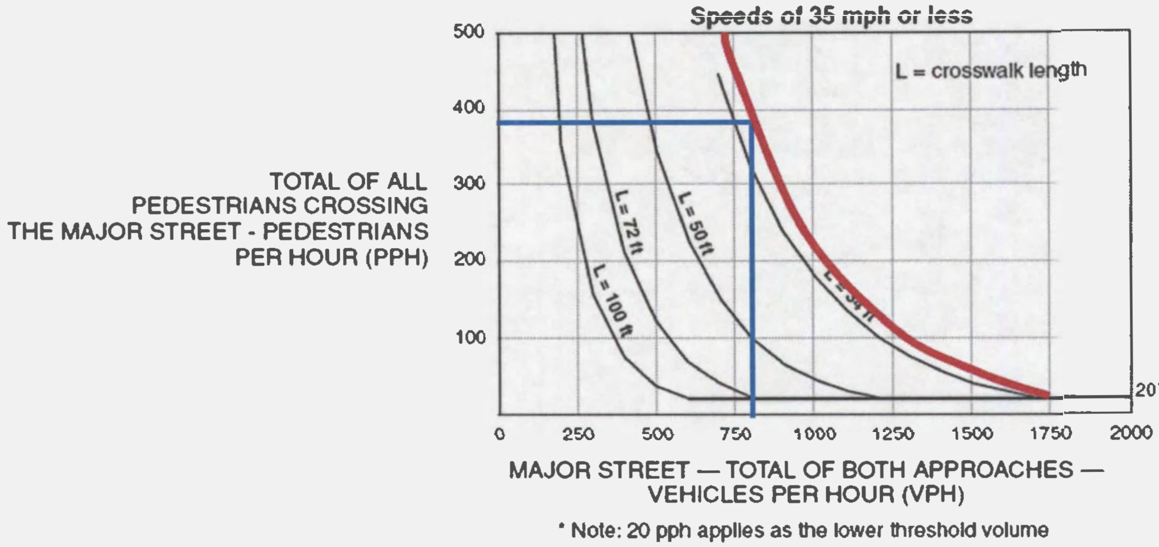


Figure 3.17. AM Roosevelt PHB Standard Results.

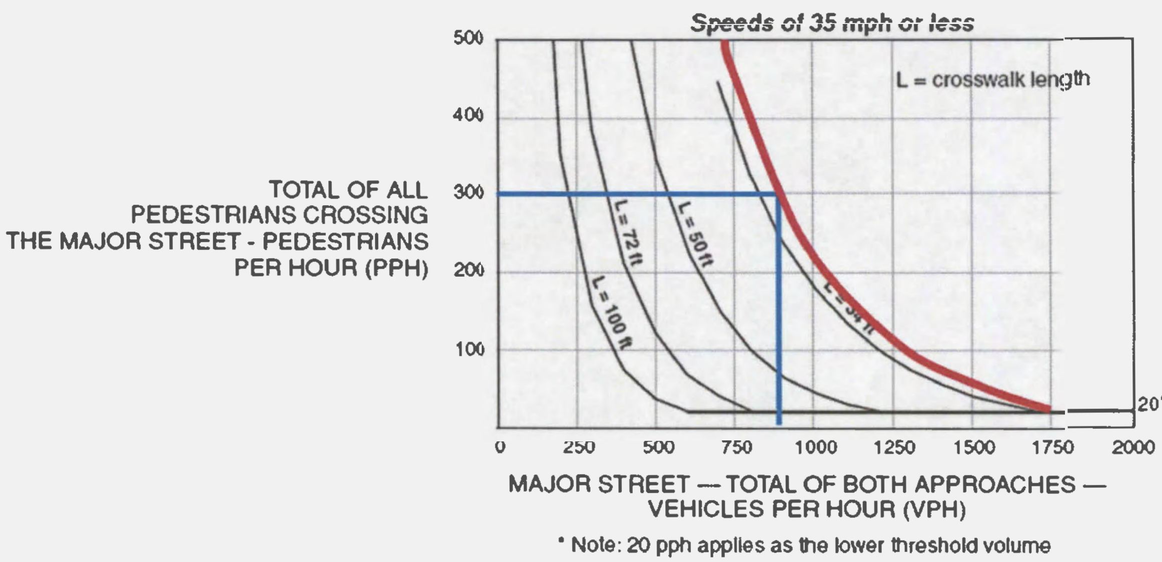


Figure 3.18. PM Roosevelt PHB Standard Results.

The current PHB standards require drastic school zone correction (see Table 3.2). No study site was closer than 73% below the required PPH needed to install a PHB.

Table 3.2. PHB School Zone Results.

Location	Testing Period	Actual PPH	Required PPH	Required Increase in PPH
Centennial	**AM**	**26**	**500**	**1823.1%**
Carl Ben Eielson	**AM**	**26**	**45**	**73.1%**
Roosevelt	**AM**	**31**	**385**	**1141.9%**
Roosevelt	**PM**	**24**	**300**	**1150.0%**

Regardless, under section 4F.06 of the 2009 MUTCD, PHBs can still be installed if they meet one of the nine standard warrants. This stipulation makes these figures irrelevant, especially at the school zone context. For PHBs to be a viable consideration for engineers designing school crosswalks, it is essential that the MUTCD have school zone considerations and/or alterations to standards regarding this control device.

3.6. Recommended Modified Analysis

The first recommended correction to current PHB standards is the timeframe used for analysis. As described in the pedestrian volume section (section 3.4.1) the time periods in the AM after school has started and over thirty minutes before school has started has little to no pedestrian activity at school zones. Similarly, during the PM time period, the 15 minute interval before school had ended and any interval thirty minutes after school was dismissed had little to no activity. When considering school zone pedestrian activity, warranting should consider equivalent peak hour flows. This means, the engineering study should determine the peak 15-minute pedestrian volume and multiply this number by 4 to determine the equivalent peak hour. 30 minute, 10 minute, and 5 minute intervals may also be deemed acceptable at certain locations. Due to the availability of 15 minute data, this thesis will focus on intervals of this magnitude.

Traffic also plays a major part in determining if a pedestrian signal is warranted at a specific location. If there are adequate gaps in traffic for pedestrians to cross then a PHB or signal should not be warranted. It is recommended that wherever there are more pedestrians than available gaps per 15 minute period at a school crossing, this location should be considered for PHB installation. Comparing gaps to pedestrians is more useful than gaps to minutes in a study period. For example, if a 15 minute interval had 16 adequate gaps it would not require a pedestrian signal but if this same interval had 25 pedestrians there could be significant safety issues arising during this period. Figures 3.19 and 3.20 visually display this idea. This procedure is typically not feasible at non-school zone related areas where peak pedestrian intervals are longer than 15-30 minutes. As seen on the figures, there are numerous intervals where there are more pedestrians than available gaps. Hence, it is recommended that these intervals be used to test whether a school crossing requires a signal.

The final recommendation for PHB school zone correction is a lowered tolerance for acceptable pedestrian volumes. Due to the unpredictable nature of school aged children, it is essential that these locations be handled with extra care and safety. Lowering the level of required pedestrian activity to warrant the PHB would provide this extra care and safety. One solution to remedy this problem is to use the PHB figure corresponding to vehicle speeds over 35 mph for school zone PHB allocation. This figure requires lower levels of pedestrian activity due to the increased danger that high speed roadways present. The same type of precautionary measures that the MUTCD prescribes for high speed roadways should be translated to school crossings due to the pedestrian-vehicle conflict risk that uncontrolled school aged children pose. Using current PHB Figures provides an option that does not require new study methodology to create additional figures.

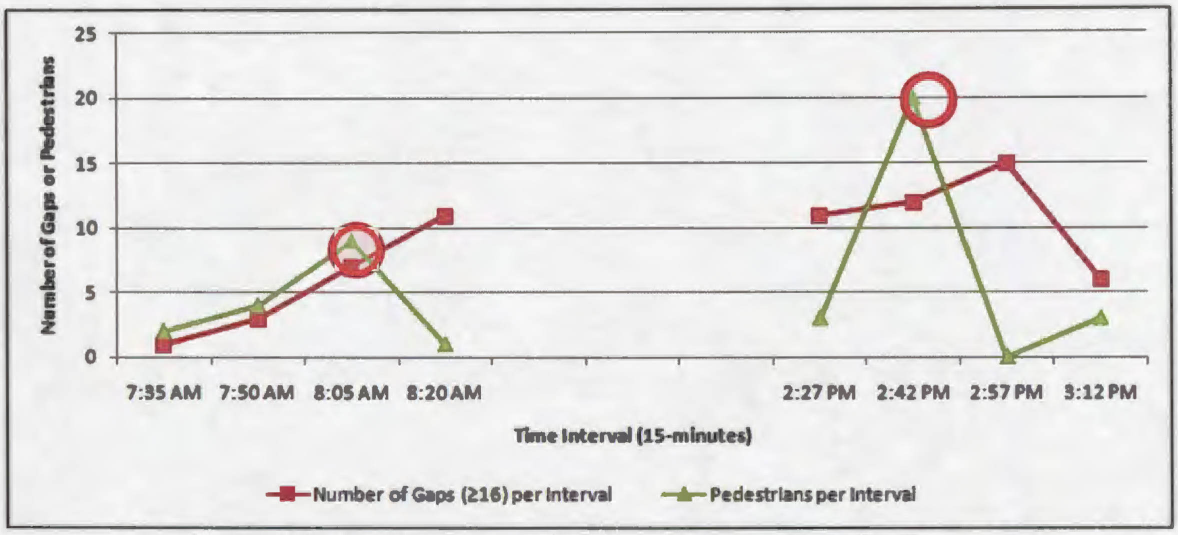


Figure 3.19. Pedestrian versus Gap Available Analysis for Centennial.

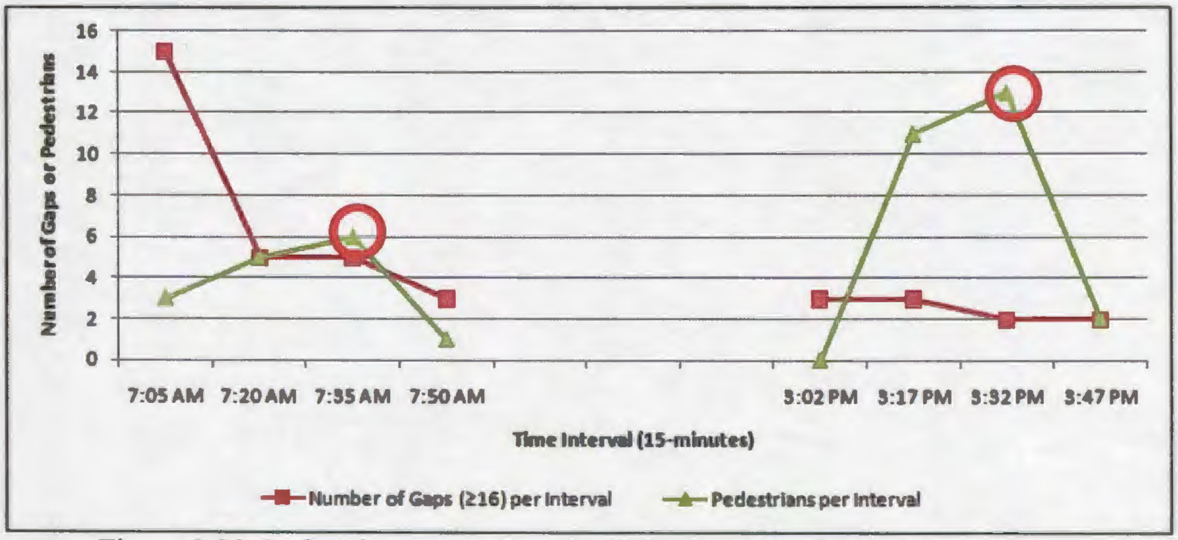


Figure 3.20. Pedestrian versus Gap Available Analysis for Carl Ben Eielson.

To check these recommendations for adequacy one interval from the AM and one from the PM testing periods were chosen from each of the four test sites. Due to the prescribed recommendations, the testing period will be equivalent rates of flow in regards to pedestrian volume. Similarly, it is important to use the equivalent vehicular rate of flow for the same 15-minute interval to get the appropriate results. Horace Mann will be used as the control for this procedure to insure that the recommendations are not too light. Table 3.3 below shows the intervals chosen, and Figures 3.21-3.28 show the results of the new testing scheme. Following these figures, Table 3.4 lists the results of the recommended PHB school zone procedure. The testing intervals for Centennial and Carl Ben Eielson were chosen by taking the interval with the greatest difference between pedestrian volume and gaps for the specific interval (highlighted with a red circle in Figure 3.20). Gap data is not available for the Roosevelt and Horace Mann test sites; consequently, the interval with the highest pedestrian volume was utilized for testing.

Table 3.3. List of Testing Parameters for PHB School Zone Corrections Testing.

Location	Test Period	Time Until School Begins/Ends	Pedestrian Volume (Ped/15-min)	Ped-Equivalent Volume (PPH)	Vehicle Volume (veh/15-min)	Veh-Equivalent Volume
Centennial	**AM**	**15-0 minutes before**	**9**	**36**	**209**	**836**
Centennial	**PM**	**0-15 minutes after**	**20**	**80**	**137**	**548**
Carl Ben Eielson	**AM**	**15-0 minutes before**	**6**	**24**	**273**	**1092**
Carl Ben Eielson	**PM**	**15-30 minutes after**	**13**	**52**	**339**	**1356**
Roosevelt	**AM**	**30-15 minutes before**	**17**	**68**	**227**	**908**
Roosevelt	**PM**	**15-30 minutes after**	**15**	**60**	**252**	**1008**
Horace Mann	**AM**	**45-30 minutes before**	**2**	**8**	**191**	**764**
Horace Mann	**PM**	**0-15 minutes after**	**4**	**16**	**114**	**456**

Using the recommended corrections for PHB standards in school zones, the three school crossings that passed Warrant 5 standards also passed these corrected PHB standards: Centennial, Carl Ben Eielson, and Roosevelt. Similarly, the school crossing that did not meet Warrant 5 standards, Horace Mann, also did not meet these corrected standards. The AM Centennial and AM and PM Roosevelt results were very close to not

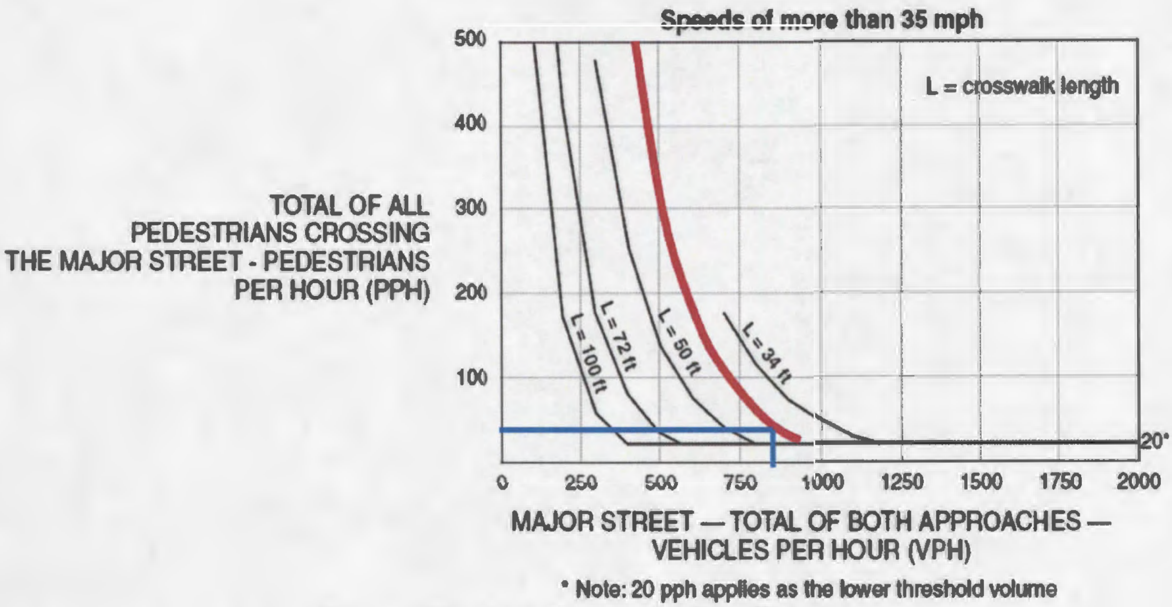


Figure 3.21. AM Centennial Test Results.

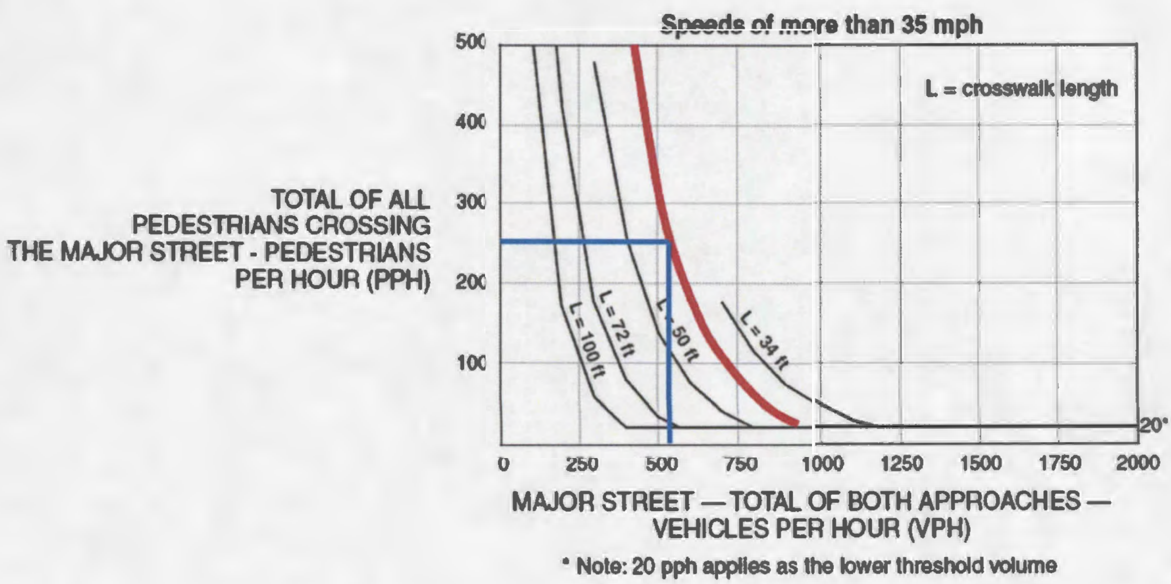


Figure 3.22. PM Centennial Test Results

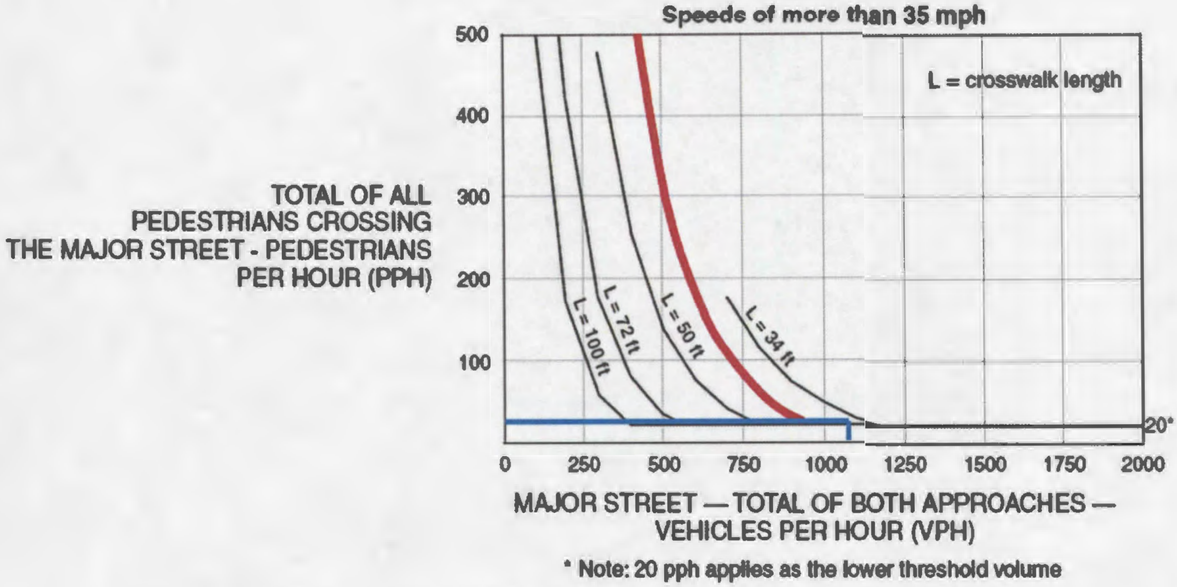


Figure 3.23. AM Carl Ben Eielson Test Results

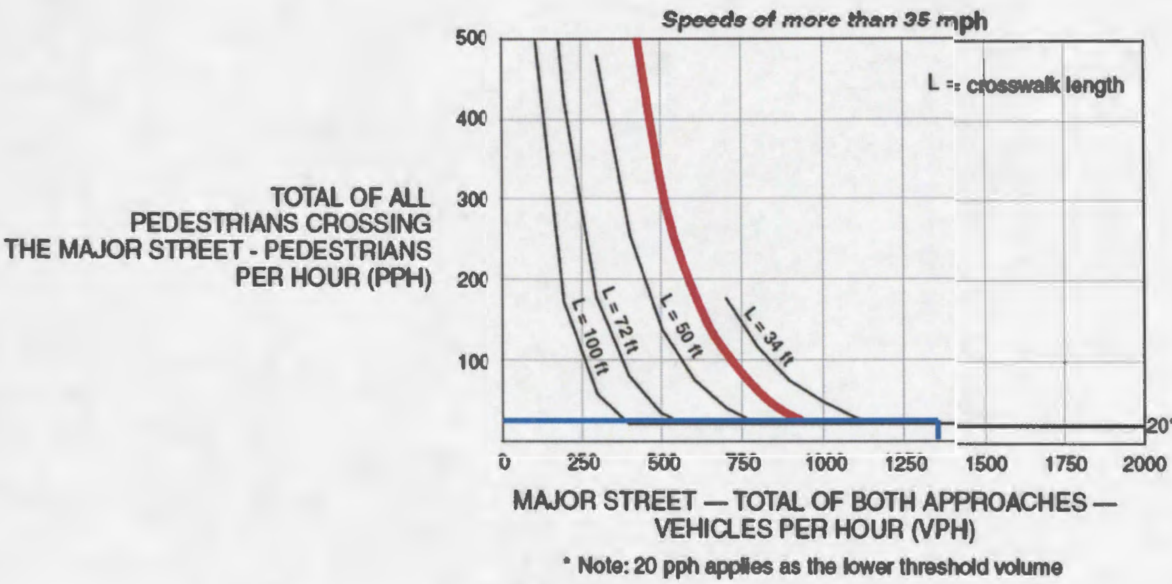


Figure 3.24. PM Carl Ben Eielson Test Results

meeting these standards. It is recommended that in situations such as this, it is better to err on the side of pedestrian safety and install the pedestrian beacon.

If the students participating in the morning MS fundraiser walk were discounted, then the AM study would not have passed the new recommended standards. It is important to note that much like Warrant 5; only one testing periods needs to meet these standards to

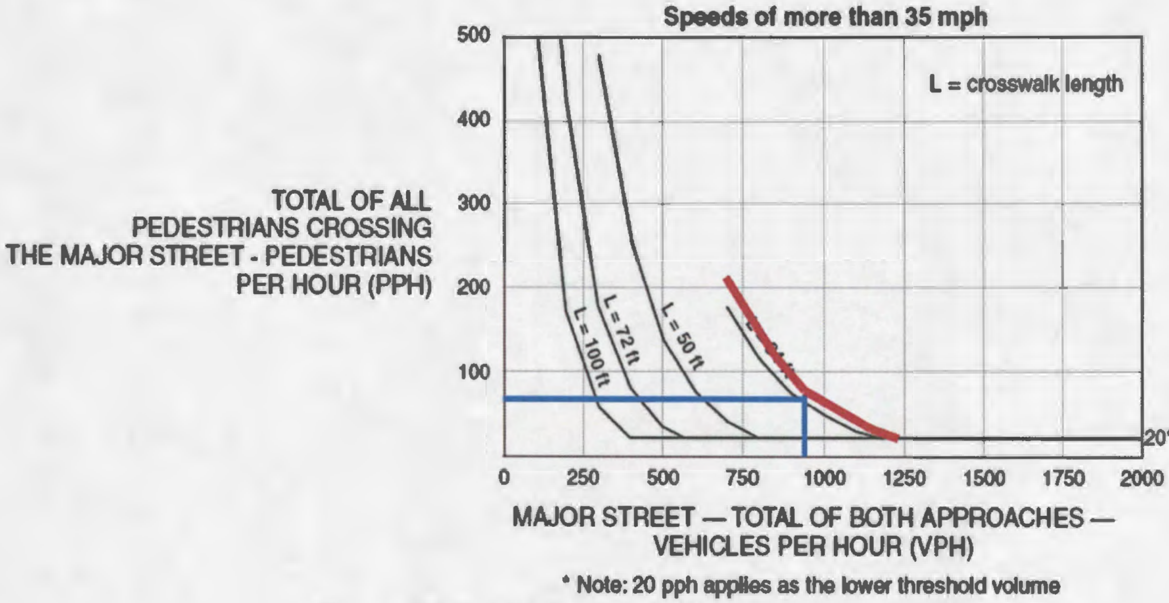


Figure 3.25. AM Roosevelt Test Results.

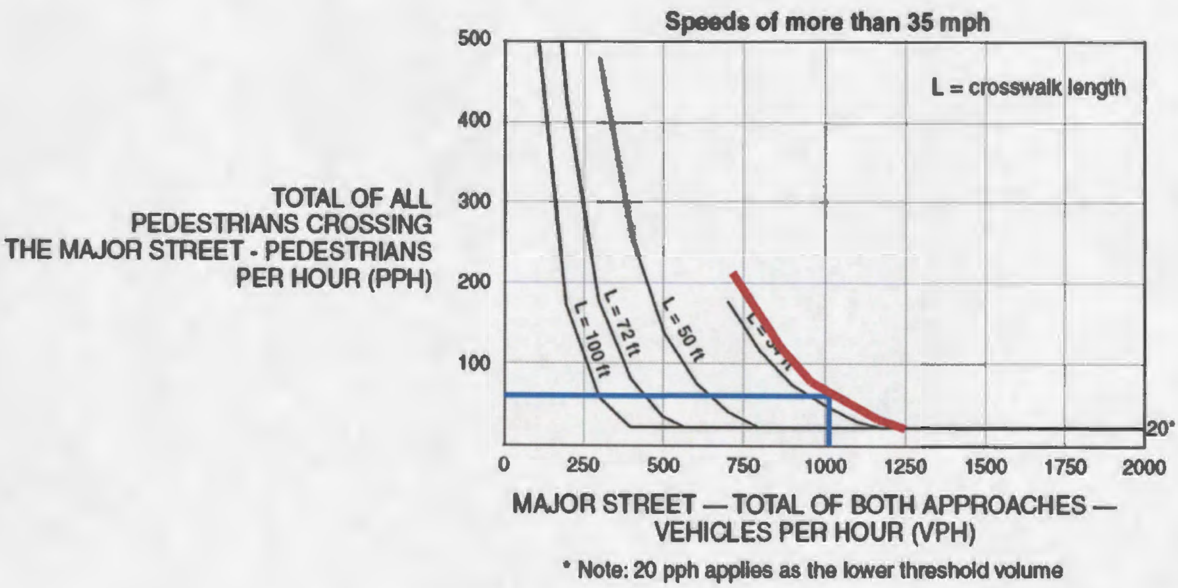


Figure 3.26. PM Roosevelt Test Results.

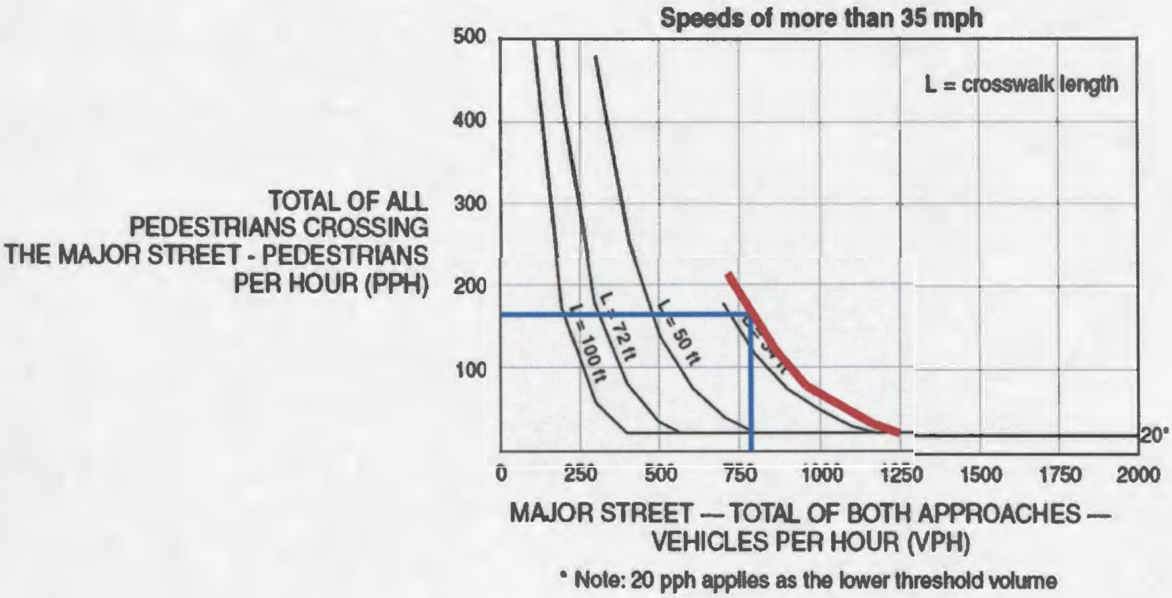


Figure 3.27. AM Horace Mann Test Results.

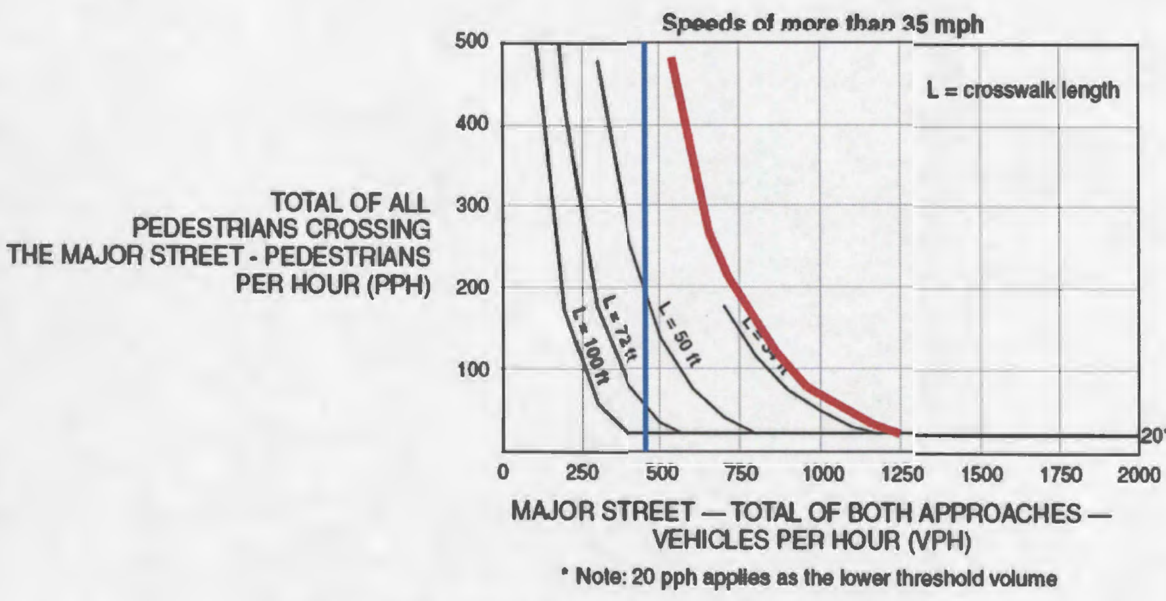


Figure 3.28. PM Horace Mann Test Results.

warrant installation of a school crossing PHB. As a result, eliminating these students is irrelevant because the PM study passed the recommended standards permitting the installation of a PHB at this location.

Finally, successful testing periods were not the same for some of the study sites. For example only the PM study period for Centennial passed Warrant 5 standards whereas only the AM period passed recommended PHB corrections. Similarly the AM Carl Ben Eielson study period which did not pass Warrant 5 standards passed the recommended corrections. This indicates that there is a slight variance between the Warrant 5 and the new recommended corrections. This variance can be accredited to the equivalent rate of flows utilized in the recommended PHB corrections that was similarly recommended as an improvement to current Warrant 5 standards. Using equivalent rates of flow allows engineers to focus on the specific problem intervals as opposed to diluting the results over a full hour.

Table 3.4. Recommended PHB School Zone Corrections Results

Location	Test Period	Ped-Equivalent Volume (PPH)	Required PPH for PHB Installation	Pass or Fail New Standards
Centennial	**AM**	**36**	**35**	**Pass**
Centennial	**PM**	**80**	**250**	**Fail**
Carl Ben Eielson	**AM**	**24**	**20**	**Pass**
Carl Ben Eielson	**PM**	**52**	**20**	**Pass**
Roosevelt	**AM**	**68**	**65**	**Pass**
Roosevelt	**PM**	**60**	**60**	**Pass**
Horace Mann	**AM**	**8**	**155**	**Fail**
Horace Mann	**PM**	**16**	**INF**	**Fail**

In conclusion, when applying PHB standards, it is critical to note that these standards are not designed for and cannot be applied at school zone locations. School zones require increased levels of safety similar to roadways with high speed traffic that current PHB standards do not consider. When considering PHB or signal installation at school zones, engineers should consider equivalent rates of flow to determine the need for a signal or PHB. These equivalent rates of flow should stem from peak 15-minute pedestrian and traffic intervals. This concept is due to the great variability of pedestrian traffic during the peak pedestrian volume hour at school zones. Additionally, crosswalk controls should be considered when there are more pedestrians in an interval than available gaps. Finally, when determining school hours, the times associated with high pedestrian volumes should not correspond with peak traffic volume hours when possible. These high pedestrian volume periods are generally associated with school beginning and end times.

The unique approach and analysis proposed in this thesis is one possible solution to remedy the limitations of current MUTCD PHB standards. This approach allows PHB application at school zones using current PHB related figures and data collection. Although the recommended PHB standards proposed in this thesis for school zones need not be adopted by the MUTCD, it is essential that the MUTCD have considerations for PHB application at school zones.

3.7. Summary

This chapter presented a comparative analysis of MUTCD Warrant 5 against new PHB standards, which were incorporated in December, 2009. The analysis was based on pedestrian volume, vehicle volume, and gaps data collected at four different crosswalk sites in school zones in Fargo, North Dakota. The data provided the basis for several recommended improvements to current MUTCD standards for better crosswalk control application at school zones as well as improvements to school zone policy in general. This chapter also included recommended steps to more appropriately apply the MUTCD PHB standards to school zone sites to get consistent determinations and evaluations.

CHAPTER 4. EVALUATION OF PHB AND CONVENTIONAL CONTROLS AT SCHOOL ZONES

The focus of this chapter was to determine the most effective crosswalk control device for balancing pedestrian safety and vehicle convenience at school crossings. The strategy for determining this balance will be to compare the PHB against conventional devices of crosswalk control at school crossings. The conventional devices tested in this chapter are marked crosswalks with a corresponding pedestrian sign and pedestrian signals.

4.2. Methodology

Three crosswalk control devices were selected for evaluation based on three measures of effectiveness: motorist compliance, pedestrian delay, and motorist delay. The three crosswalk control alternatives were marked crosswalks with a corresponding pedestrian sign, conventional pedestrian signals, and the PHB. First, data were collected in regards to motorist compliance in percentage of those who complied, pedestrian delay in seconds per pedestrian, and motorist delay in seconds per vehicle. This data was graded based on HCM Level of Service (LOS) Tables and one original LOS Table. Finally, the crosswalk control device with the highest average Level of Service grade will be concluded as the ideal device for balancing pedestrian safety and motorist convenience at school crossings. Figure 4.1 depicts this methodology in the form of a flow pattern.

To grade the specific controls, numerous tables from the 2000 Highway Capacity Manual (HCM) will be utilized. The HCM tables for level of service (LOS) regarding motorist delay at signalized and unsignalized intersections as well as pedestrian delay at signalized and unsignalized intersections were used. Tables designed for intersections were

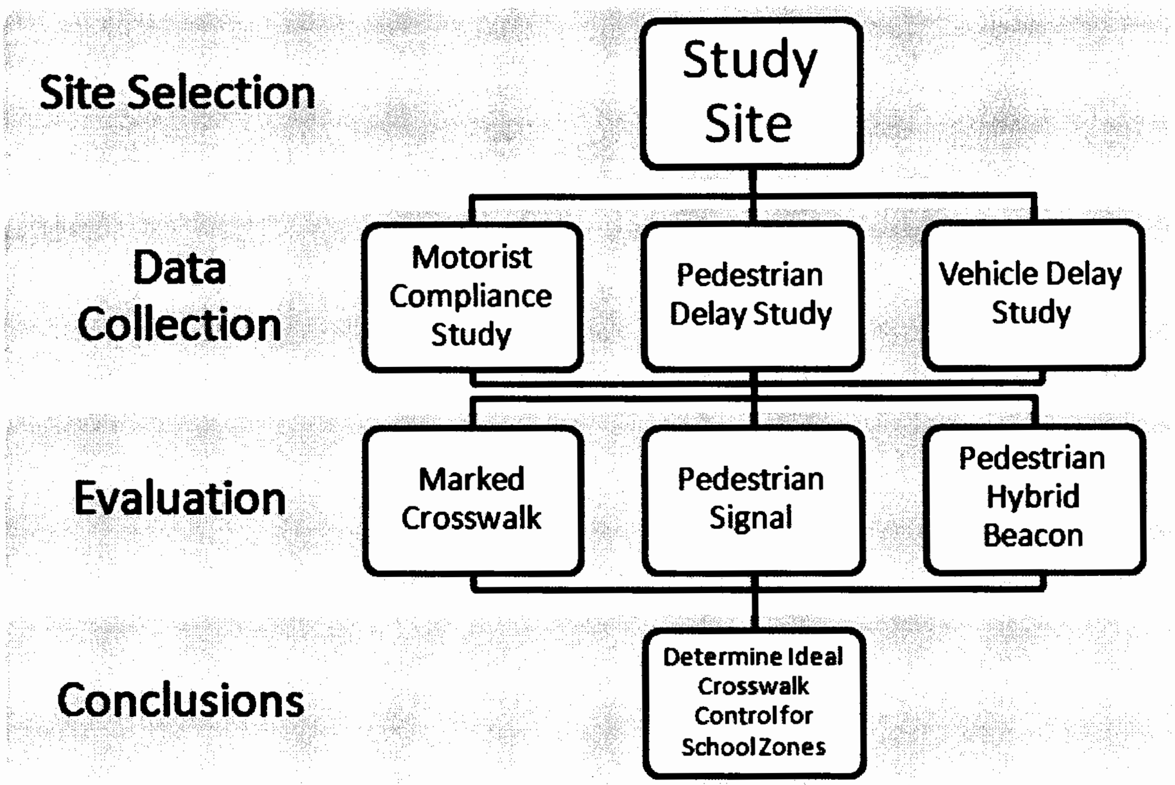


Figure 4.1. Methodology for Evaluation of Crosswalk Controls.

used because the HCM does not provide LOS Tables for the midblock context. Due to the increased complexity of intersection crosswalks in comparison to midblock crosswalks, it can be assumed that the acceptable delay at midblock locations would be shorter. Utilizing the intersection delay criteria provides a conservative approach for LOS estimation. It is important to note that although the PHB is not technically considered a "signal," the HCM does not provide tables regarding traffic control devices of this nature. Similarly, the HCM LOS criterion for unsignalized intersections is not intended for locations with marked crosswalks. The HCM, once again, does not provide alternatives for this context. Consequently, the tables developed for standard traffic control signals was utilized when dealing with the PHB and the tables developed for unsignalized intersections were utilized when dealing with the marked crosswalk in this study. Although these Tables are not designed for these specific control devices, the differences are insignificant enough to disregard.

The HCM also does not provide LOS criteria regarding compliance at any context. Consequently, an original LOS Table was created. The compliance values selected were intended to be very conservative and based on the idea that no school crossing is ideal unless it has a 100% compliancy rating or very near to it. It was decided that any crosswalk control device demanding a 98% compliancy rate or better was of LOS A. This means that no more than 2 out of every 100 motorists can be noncompliant at a specific traffic control device to obtain a LOS rating of A. The following grades grew by 2+N compliancy percentage points for each subsequent level until 80% compliancy was obtained. N stands for the number of grades after LOS A (i.e. B=1, C=2, etc.). This type of progression was utilized to make it increasingly difficult to achieve higher LOS values. Any compliancy percentage below 80% is given a LOS value of F and considered not suitable for school zone design.

Table 4.1 depicts the LOS grades provided by the HCM as well as the original motorist compliance grades. Each LOS grade was given a rating from 0-5, 0 being the lowest and 5 being the highest. LOS grades of A or B is desired when designing a school

Table 4.1. LOS and Rating Value Table.

Level Of Service	Motorist Delay (sec)		Pedestrian Delay (sec)		Compliance (%) Signalized/ Unsignalized	Rating Value
	Signalized	Unsignalized	Signalized	Unsignalized		
A	≤10	≤10	<10	<5	≥98	5
B	>10-20	>10-15	≥10-20	≥5-10	<98-95	4
C	>20-35	>15-25	>20-30	>10-20	<95-91	3
D	>35-55	>25-35	>30-40	>20-30	<91-86	2
E	>55-80	>35-50	>40-60	>30-45	<86-80	1
F	>80	>50	>60	>45	<80	0

Source (Motorist and Pedestrian Delay): TRB, 2000 crossing and as a result corresponds with the ratings of 5 and 4 respectively. Once LOS grades were determined for motorist delay, pedestrian delay, and motorist compliance, these grades were converted into their corresponding ratings and averaged for each crosswalk. The device with the highest value was considered to be the ideal crosswalk control alternative in regards to pedestrian safety and motorist convenience at school zones.

4.3. Description of Study Sites

The criteria for selecting study sites for Chapter 4 considered three separate characteristics. First, each crossing had to be located within a school zone, specifically within or outside of a 20 mph speed controlled zone during school related times for consistency. Second, each crossing had to be configured as a midblock or operate as a midblock. Finally, sites were selected with similar crosswalk geometries and traffic volumes. This was intended to impose additional consistency for comparison purposes.

The study sites evaluated in Chapter 4 were identical to Chapter 3, with the exception of Carl Ben Eielson being eliminated from the study. Since this evaluation compares marked crosswalks, pedestrian signals, and PHBs, Carl Ben Eielson was eliminated from analysis due to its location being completely uncontrolled. Another major difference was that the Centennial crossing was studied twice (see Figure 4.2). First the Centennial crosswalk was evaluated as a marked crosswalk for motorist compliance, pedestrian delay, and motorist delay. Next it was reevaluated after the PHB was installed for the same test parameters. Using the same testing location for two of the three crosswalk controls eliminated the potential effect that varying crosswalk geometries and traffic volumes could have on the different control devices. Unfortunately the City of Fargo only has two midblock pedestrian signals, Roosevelt and Horace Mann. These two locations both have very different crosswalk widths and traffic volumes compared to Centennial (see Table 3.1). The way this problem was solved was by averaging the data collected at Roosevelt and Horace Mann in an attempt to create as unbiased results as possible.

Picture on the left is of the Centennial test site before PHB installation. Pictured on the right is of the Centennial study site after PHB installation. Both photographs are shot from looking from the Northeast of the crosswalk.

Figure 4.2. Centennial Test Site (Before and After PHB installation).

4.4. Data Collection

In this section, the specific tests performed are documented and how they were configured, operated, and recorded are explained. These tests will determine which crosswalk control device is superior in improving the areas of pedestrian safety and motorist convenience and which control has the ideal balance of the two. Pedestrian safety will be determined by studying motorist compliance and pedestrian delay, whereas motorist convenience will be determined by studying motorist delay.

4.4.1. Motorist Compliance

Motorist compliance, in regards to this study, is the percentage of vehicles that stop or yield when required to do so. Motorist compliance was recorded using a tally sheet during the pedestrian volume and motorist delay studies as well as using the JAMAR TDC-12 device during the traffic volume studies. The tally sheet recorded the number of noncompliant vehicles who refused to stop for the specific control device whereas the JAMAR traffic data collecting device was used to count the amount of pedestrian-vehicle conflicts.

A pedestrian-vehicle conflict occurs when a motorist and/or pedestrian has to take some action, such as change in direction, speed, or both in order to avoid collision, or to adhere to some traffic controlling device. A number of studies have used conflicts as a measure of effectiveness for identifying pedestrian safety problems, evaluating traffic control devices, and comparing pedestrian accommodation designs (Robertson, 1994). Conflicts, as defined in this study, are the number vehicles that had to stop or slow down at a marked crosswalk for a pedestrian to cross the street, or because a pedestrian signal or PHB warranted a stop.

Using pedestrian-vehicle conflicts as one parameter and the amount of motorists who refused to stop or slow down for the specific traffic control device as another, it is possible to determine motorist compliance. Motorist compliance can be calculated as the number of pedestrian-vehicle conflicts divided by that same number with the addition of those who refused to stop for the traffic control device. The resulting motorist compliance was then input into Table 4.1 to determine the corresponding LOS grade for each individual crosswalk control device. High motorist compliance is desirable because it determines the percentage of drivers who obey the specific crosswalk control device.

4.4.2. Pedestrian Delay

Pedestrian delay is the amount of time lost by a pedestrian waiting for a adequate gap in traffic (Robertson, 1994). Pedestrian delay at marked crosswalks is the amount of time the pedestrian waits for motorists to stop and grant them right-of-way. If cars are not willing to stop, the pedestrian delay time directly correlates with the amount of time it takes the pedestrian to find an acceptable gap in traffic to cross the intersection. Pedestrian delay at intersections controlled by a signal or beacon directly correlates with the amount of time it takes the signal or beacon to respond to the pedestrian's call and stop opposing traffic to grant them access into the crosswalk. Low pedestrian delay is desired to prevent impatient pedestrians from crossing the street without the assistance of a crosswalk control device. Traversing busy streets without the assistance of a crosswalk control device can be extremely dangerous.

To record pedestrian delay, the observer used a stopwatch and a tally sheet. Each pedestrian delay was recorded and then averaged together for the crosswalk control device to determine delay per pedestrian. This value was input into the corresponding HCM Table to output a LOS grade.

In regards to the marked crosswalk context, the delay time was defined as the amount of time between when the pedestrian stopped at the curb of the street until he or she started crossing the street. Typically, for pedestrian activated signals, pedestrian delay is calculated from the beginning of the "flashing don't walk" phase until the ensuing "walk phase" if a pedestrian is present. This section of time accounts for all of the "flashing don't walk" and "solid don't walk" phases. These phases account for a portion of the red, the entire minimum green, and the entire yellow phases. In this particular study, pedestrian delay is a measure of safety and not a measure of convenience. As a result, pedestrian delay will discount the time a pedestrian waits during the yellow and ensuing all red phase in which the pedestrian still has a don't walk signal. These portions of time are disregarded because it can be assumed that a pedestrian is unlikely to perform a risk taking behavior if the individual knows that the signal will be shortly changing and allowing them safe passage across the road. This same method of pedestrian delay timing will be used at PHBs as well. This is important to note due to the flashing yellow phase installed in the PHB timing scheme. This additional six seconds would significantly alter the pedestrian delay results when comparing a pedestrian signal to a PHB.

4.4.3. Motorist Delay

Motorist delay is the time lost by a motorist due to causes beyond the control of the driver (Robertson, 1994). The delay in this study is pedestrian instigated. The motorist delay time is the time a motorist waits at a marked crosswalk for a pedestrian to pass or the time a vehicle waits at a control signal or PHB for the pedestrian phase to end and the light to turn green.

The JAMAR TDC-12 device was used to calculate motorist delay. The observer firsts puts the delay study cover on the TDC and changes the collection method to delay on the device. The TDC only requires four buttons to perform this study. It has two "arrive" buttons and two "depart" buttons, which were used for the two lanes of traffic at each study site. Each car was counted when it came to a complete stop (arrival) and each car was recounted when it began to depart. This effectively recorded every cars total time at the specific crosswalk control device. The delay for each vehicle was then averaged to determine the delay per vehicle to input into the HCM Table.

Knowing when to begin timing a motorist during a delay test can be difficult at times. This is true when motorists see a crosswalk control device and instead of driving to the stop line and coming to a complete stop they slowly troll towards the device to wait for the signal to change or the pedestrian to pass. This type of motorist response has the potential to skew delay results. Fortunately, this response was witnessed at every study site which effectively neutralized the impact on the results.

4.5. Results and Discussion

In this section, collected data will be documented and analyzed. This data will be calculated and values presented for motorist compliance, pedestrian delay, and motorist delay for the three crosswalk control devices. Additionally, discussions and explanations will be provided regarding reasons for specific findings and outliers will be provided in this section.

4.5.1. Motorist Compliance

Motorist compliance was found to be 53.7% for the marked crosswalk, 100.0% for the pedestrian signals, and 99.0% for the PHB (see Figure 4.3). The most important statistic regarding motorist compliance is the sheer quantity of noncompliant motorists found at the marked crosswalk. A total of 62 drivers neglected to stop for pedestrians in the two hours of testing. One pedestrian had to wait for a total of 9 cars to pass until a motorist stopped to allow the child access to the crosswalk. An average of 2 vehicles ignored the marked crosswalk control device for each group of pedestrians. These results directly support the literature's findings that many drivers do not comply with pedestrian crossing signs and stripes and that pedestrian signals and PHB impose high levels of motorist compliance. NCHRP Report 562 found that marked crosswalks with a posted speed of 25 mph had an average compliance rate of 61% for staged pedestrian crossings and 91% for field observation. This is particularly concerning that at a school crossing, with slower speeds and younger pedestrians waiting to cross, this value was actually lower than the NCHRP findings (53.7%). By rule vehicles must yield the right-of-way to pedestrians at marked crosswalks, unfortunately this rule is clearly misunderstood by motorists, pedestrians, and law enforcement alike.

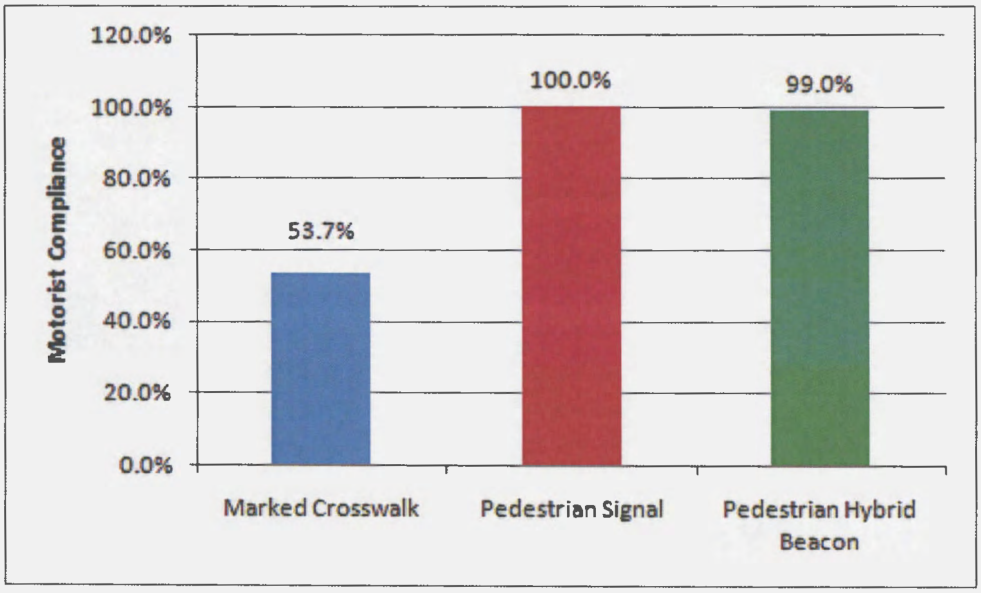


Figure 4.3. Motorist Compliance

It is important to note that much of the compliance at marked crosswalks was forced compliance. When one car stopped for a pedestrian every car behind them would stop to prevent a collision. Since the pedestrian elicited the driver to stop, this was deemed a conflict. It is impossible to predict if these cars would have stopped for the pedestrians if not forced to do so by preceding vehicles. Since the morning study had a higher traffic volume than the afternoon, this condition of forced compliance impacted this study period by a greater margin. Many times when one motorist would stop to allow a pedestrian access to the crosswalk, a queue of several cars would build up behind them in the morning.

The PHB only incurred one noncompliant driver. This driver gave the impression that he was lost as he scrambled to read street signs. His noncompliance appeared to be accidental. The pedestrian signal experienced a 100% compliancy percentage which should be intuitive due to the frequency that a typical driver faces signals with this design. Tables 4.2 and 4.3 show the motorist compliance results separated into 15-minute intervals.

4.5.2. Pedestrian Delay

After discussing the motorist compliance and pointing out that only 54% of vehicles stopped for pedestrians at a marked crosswalk, naturally one would assume that marked crosswalks would have the longest pedestrian delay results. As Figure 4.4 displays, the opposite is in fact true. Pedestrian delay at marked crosswalks is less than half the time that the pedestrian signals and PHB incurred. The discrepancy between the pedestrian delay results at the marked crosswalk versus the pedestrian signal and PHB is not as significant as it first appears. According to the HCM; pedestrians tolerate smaller delays at unsignalized intersections than at signalized intersections. As a result, the marked crosswalk (5.26 seconds per pedestrian), the pedestrian signals (12.99 seconds per pedestrian) and the PHB (12.29 seconds per pedestrian) all received LOS grades of B based on HCM LOS criteria.

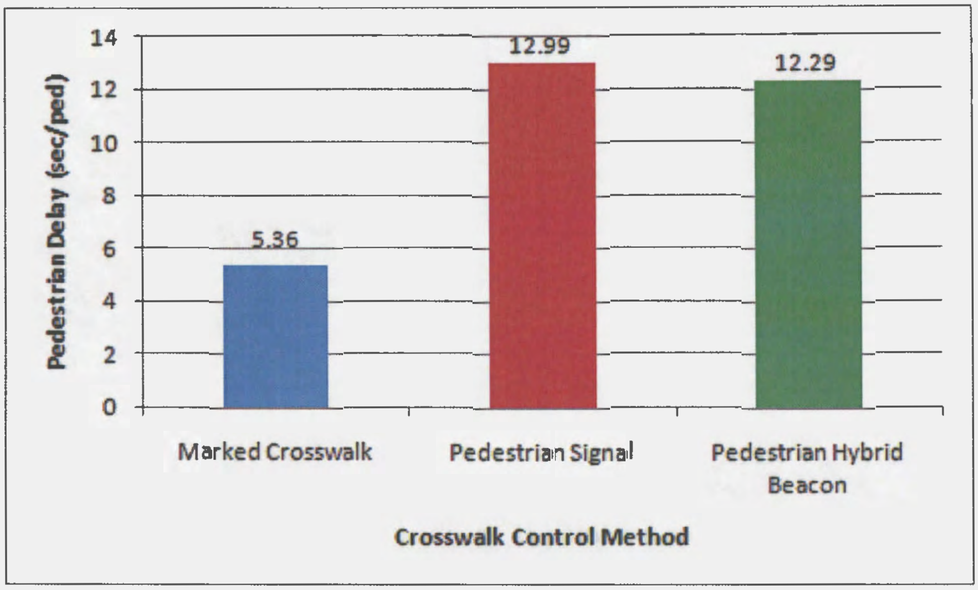


Figure 4.4. Pedestrian Delay.

The low pedestrian delay values recorded at the marked crosswalk can be partially credited to the aggressive nature many of the pedestrians exhibited at this location (as alluded to in section 3.4.3). Many pedestrians stepped out onto the street and induced a conflict instead of giving the cars an opportunity to be noncompliant. These pedestrians appeared accustomed to the low level of compliance at this crosswalk and forced compliance upon the vehicle and in turn put their safety in jeopardy in the process.

The majority of the delay at the pedestrian signal and PHB occurred during periods with high pedestrian volume. This is due to the minimum green phase that the two pedestrian signals and the PHB have installed into their timing schemes. This minimum green phase requires that vehicular movements will always receive a minimum amount of green time between pedestrian signal or PHB actuations. During periods of peak pedestrian flow, the signal or PHB is constantly being utilized, meaning that many times large groups are forced to wait the entire minimum green time before the signal or PHB allows them to access the crosswalk. Table 4.2 depicts the time scheme for the pedestrian signal and PHB.

As displayed in the Table, the minimum green time for Horace Mann (pedestrian signal) is 64 seconds, Roosevelt (pedestrian signal) is 62 seconds, and Centennial (PHB) is 35 seconds. Instinctively this discrepancy would appear to sway the pedestrian delay in favor of the PHB. In reality, the PHB has a 38% shorter WALK phase than the pedestrian signal and in turn services less pedestrians per activation. The reduced WALK phase creates more platoons of pedestrians subject to the entire minimum green time albeit a much shorter minimum green time than at the pedestrian signals. Even with the increased pedestrian delay, the safety and comfort of the PHB caused the pedestrian volume at Centennial to increase by almost 15%. The PM testing period in particular increased its pedestrian volume by over 50%, from 26 pedestrians to 40 pedestrians.

Table 4.2. Pedestrian Signal and PHB Timing Schemes.

Horace Mann Pedestrian Signal			Roosevelt Pedestrian Signal			Pedestrian Hybrid Beacon		
Vehicles	Time (sec)	Pedestrians	Vehicles	Time (sec)	Pedestrians	Vehicles	Time (Sec)	Pedestrians
Green	12	Don't Walk	Green	0	Don't Walk	Blank	0	Don't Walk
						Flashing Yellow	6	
Yellow	3		Yellow	3		Yellow	3.2	
Red	13	Walk	Red	13	Walk	Red	1	
	9	Flashing Don't Walk		7	Flashing Don't Walk		8	Walk
Green	64 (minimum)	Don't Walk	Green	62 (minimum)	Don't Walk	Flashing Red	8	Flashing Don't Walk
						Blank	35 (minimum)	Don't Walk

Source: City of Fargo

4.5.3. Motorist Delay

Motorist delay was found to be 2.17 seconds per vehicle for the marked crosswalk, 19.89 seconds per vehicle for the pedestrian signals, and 18.04 seconds per vehicle for the PHB (see Figure 4.5). Intuitively the marked crosswalk had the lowest motorist delay of the three control devices. With essentially only half of the people stopping for pedestrians at marked crosswalks, delay became an option for the motorist.

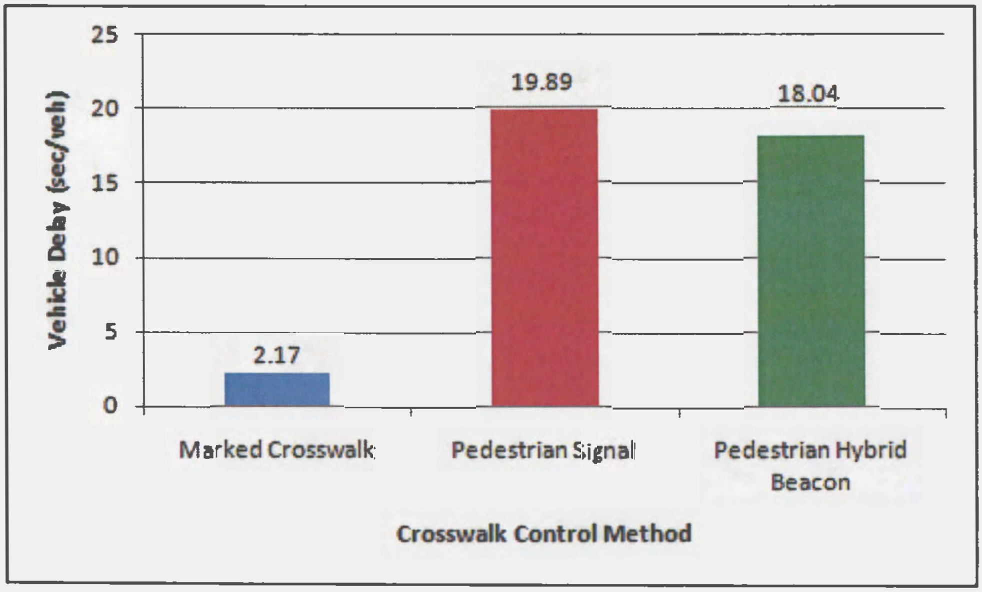


Figure 4.5. Motorist Delay.

One surprising statistic in this study was the miniscule difference in motorist delay between the pedestrian signal and the PHB. This was undoubtedly due to the motorists' unfamiliarity with the device. Only 6.86% (7 out of 102) of vehicles utilized the PHB correctly. The remaining vehicles, other than the one noncompliant driver, waited at the PHB until the flashing red phase ended and the beacon went blank. This eliminated the potential motorist delay benefits that can be achieved when the motorist departs during the flashing red phase after the pedestrians have crossed safely.

After interpreting the timing data for the pedestrian signals and PHB (see Table 4.2), the 1.85 second difference in motorist delay between the two control devices is understood. The PHB has a total red phase (solid red plus flashing red) that lasts 17 seconds whereas the red phases at Horace Mann and Roosevelt are 22 seconds and 20 seconds respectively. Ultimately, 1.85 seconds isn't a considerable amount of time.

4.6. Comparative Evaluations and Related Findings

For the Chapter 4 evaluation, the intention was to determine the crosswalk control that most effectively balanced pedestrian safety and motorist convenience at school zones. To do this, pedestrian safety must be determined first. Pedestrian safety is the balance between motorist compliance and pedestrian delay. This balance is depicted on Figure 4.6. The letters displayed on this graph correlate with the LOS grades previously covered on Table 4.1. Each level of the graph represents a different LOS rating and corresponding shade of blue. As depicted on the figure, marked crosswalks received an overall LOS of F for pedestrian safety due to the control's inefficiency in the area of motorist compliance. Contrarily, the pedestrian signal and PHB were both very effective in creating safe environments for pedestrians which resulted in desired LOS ratings of B.

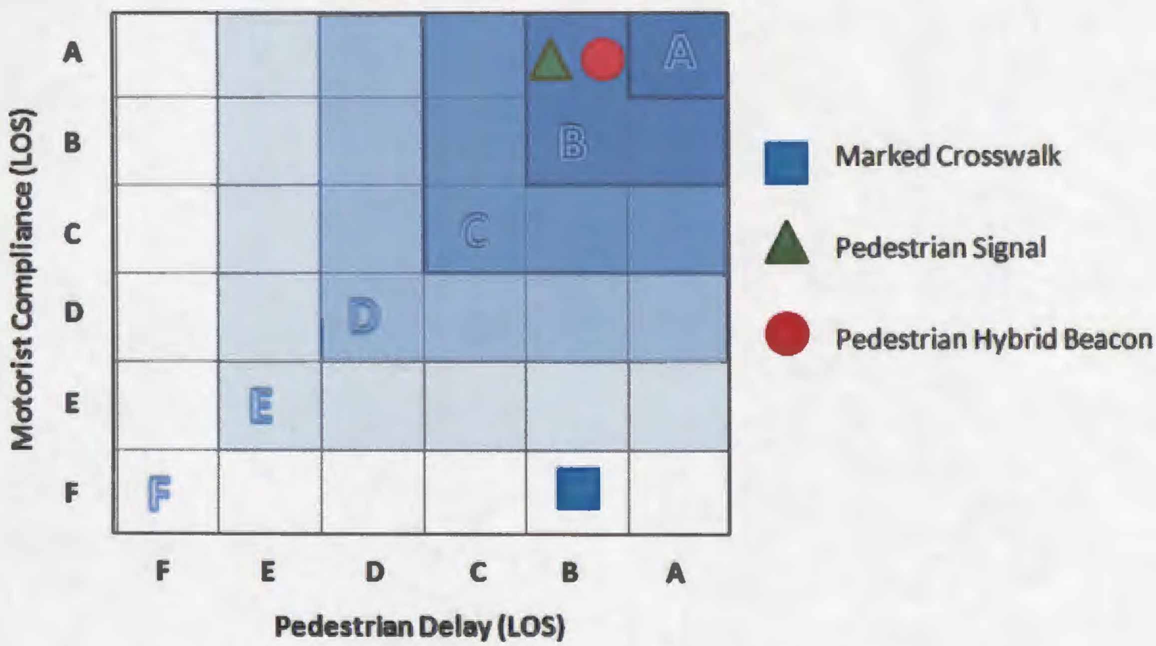


Figure 4.6. Final Pedestrian Safety Evaluation.

Once overall pedestrian safety is determined it can be compared to motorist delay to determine the final LOS grade for the crosswalk. This final LOS grade will determine which control device has superior balance of pedestrian safety and motorist convenience (motorist delay). Figure 4.7 depicts the final evaluation. Due to the aforementioned low level of pedestrian safety established at marked crosswalks, this crosswalk control device received an overall LOS rating of F. Contrarily, the pedestrian signal and PHB once again fell into the desired A-B range.

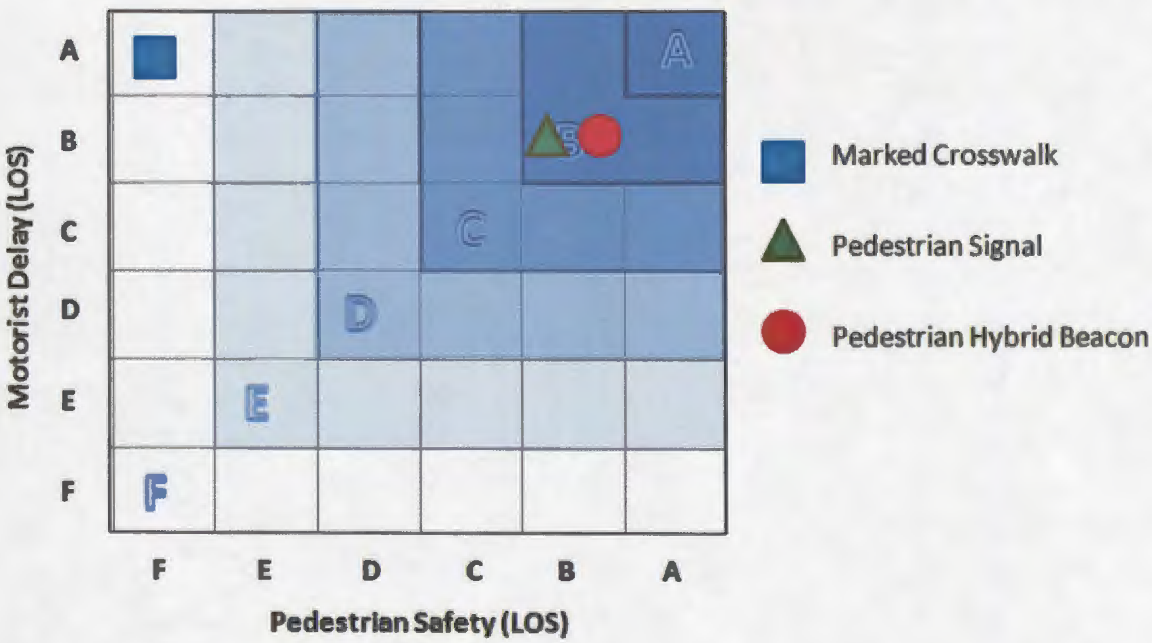


Figure 4.7. Final Evaluation.

In the final evaluation, the fact that the marked crosswalk had a significantly lower pedestrian and motorist delay compared to the other two control devices couldn't overcome the low compliance rate it received. This follows the previously stated notion that safety is the paramount concern when designing a crosswalk. Similarly motorist compliance is the paramount concern when maximizing safety. Pedestrian delay also factored into crosswalk safety but according to the HCM LOS Tables, no control device received a LOS grade lower than B, meaning the risk-taking behaviors and noncompliance caused by pedestrian delay were not a threat at these locations. Similarly, motorist delay was very low at each location. This can be confirmed with motorist delay LOS grades being at worst B, which is near ideal (see Table 4.3).

Table 4.3. Final Evaluation.

Crosswalk Control Method	Motorist Compliance		Pedestrian Delay		Vehicle Delay		Average
	Percent	LOS (Value)	sec/ped	LOS (Value)	sec/veh	LOS (Value)	LOS (Value)
Marked Crosswalk	**53.7%**	**F (0)**	**5.36**	**B (4)**	**2.17**	**A (5)**	**C (3.00)**
Pedestrian Signal	**100.0%**	**A (5)**	**12.99**	**B (4)**	**19.89**	**B (4)**	**B-A (4.33)**
PHB	**99.0%**	**A (5)**	**12.29**	**B (4)**	**18.04**	**B (4)**	**B-A (4.33)**

School zones are unique contexts due to the unpredictable nature of young pedestrians. Research regarding pedestrian-vehicle interactions at school zones as well as HCM tables regarding pedestrian delay, motorist delay, and motorist compliance in school zones would be a great step forward in the area of consistent design in this context. It was also stated earlier that the current HCM has not addressed pedestrian or motorist delay at the midblock context or motorist compliance at any context. These advances in crosswalk evaluation measures could benefit uniform design of crosswalks.

Due to the low level of proper utilization at the PHB, it is highly recommended that the City of Fargo administer some sort of PHB public outreach program to inform citizens of the new crosswalk control device. Public outreach could be achieved through television, radio, brochures at schools, and miscellaneous other possibilities. Public outreach is recommended over formal classroom education programs because in the literature review Dumbaugh & Frank (2007) found that formal motorist education programs in classroom settings do not exhibit any positive safety benefits. Another option would be to post a sign informing motorists that it is acceptable to depart once the flashing red phase has begun and pedestrians have safely passed through the crosswalk. These recommendations would undoubtedly lower the motorist delay. If the PHB was able to reduce motorist delay by a significant amount, it would make the PHB the ideal crosswalk control device for school zones and completely change the way engineers in Fargo design for this context. Engineers in other cities are urged to consider public outreach and informative signs if they chose to install PHBs in school zones for pedestrian safety and motorist delay considerations.

Similar public outreach methods could increase motorist compliance at marked crosswalks. Additionally, it was observed during the Centennial marked crosswalk studies that police enforcement stationed near the marked crosswalk for speed enforcement were either unwilling to reprimand noncompliant drivers or unaware of the current right-of-way rules in place at these locations. As a result, law enforcement education is one possible way to remedy the unsafe conditions present at marked crosswalks.

In conclusion, based on the results of the motorist compliance, pedestrian delay, and motorist delay studies, the most appropriate crosswalk control device for school zones is a tie between the pedestrian signal and PHB. The results for the two control devices were almost identical. They received LOS grades of A, B, and B for motorist compliance, pedestrian delay, and motorist delay respectively. The PHB has a 0.7 sec advantage in pedestrian delay and a 1.9 second advantage in motorist delay. The only difference in motorist compliance was the one noncompliant driver that the PHB incurred during its morning test period. Both of these control devices are currently the ideal balance of pedestrian safety and motorist convenience. At this time, these control devices should be the first consideration when designing a school zone crosswalk. Finally, under no circumstances should crosswalks with only markings and signs be utilized at school zones due to the low level of motorist compliance they impose.

4.7. Summary

This chapter provided an evaluation framework for taking into consideration motorist compliance, pedestrian delay, and motorist delay. The evaluation framework used HCM LOS criteria for pedestrian and vehicle delay at signalized and unsignalized intersections as well as established a related criterion for motorist compliance. The evaluation framework was applied at three different crosswalks in the City of Fargo under three different controls: a marked crosswalk, a pedestrian signal, and a PHB. This evaluation focused on demonstrating how evaluations can be made by taking into consideration the dual objective of enhancing both pedestrian safety and motorist convenience.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This chapter concludes the work of this thesis by presenting key findings and significant contributions. Additionally, recommendations for further work will be provided. It must be underscored that the conclusions and the recommendations made herein are relevant only for the contexts specified in the scope of this thesis.

5.2. Conclusions

The purpose of this section is to derive original conclusions based on the results of the three chapters that make up the body of this thesis. The three chapters were the literature review, the analysis of MUTCD PHB standards, and evaluation of PHB and conventional controls at school zones.

5.2.1. Pedestrians, Motorists, and Crosswalks in School Zones

This thesis extensively reviewed the issues related to pedestrians, motorists, and crosswalks in school zones. The past research indicates that there is a marked difference in the knowledge, experience, and behavior between young pedestrians and adult pedestrians. This discrepancy has serious safety implications that require that overall evaluation of crosswalk control devices need school zone specific research. Current practice of applying research conducted at locations outside of school zones using the general population is ignoring specific consideration necessary for young pedestrians. As a result, design and control of crosswalks in school zones require additional attention with regard to safety.

Safety of crosswalks is dependent not only on type of design and control at crosswalks, but also on how well are they complied with. Effectiveness of design is impacted by the understanding of the pedestrians' right-of-way by both pedestrians and motorists. This understanding is influenced by the knowledge, experience and behavior of pedestrians and motorists at crosswalks. Additional enforcement and education is required to improve compliance. Enforcement, however, can have resource commitment challenges for communities. It is also important to note that both pedestrian and motorist delays influence the (lack of) compliance of controls by pedestrians and motorists, and can thus compromise safety. Hence, the key challenge faced by the engineers in making decisions regarding design and control of crosswalk is to ensure that compliance of controls is enhanced as close to 100%, while minimizing both pedestrian and motorist delays.

5.2.2. Analysis of MUTCD Warrant 5 and PHB Standards

When considering PHB or signal installation at crosswalks in school zones, engineers should use the equivalent rate of vehicular and pedestrian flow within a 15-minute period rather than the hourly volume. This rationale recognizes and incorporates the fact that there is great variability in pedestrian traffic during the peak pedestrian hour in school zones. This consideration was convincingly demonstrated by the data collected and related analysis in this thesis. This consideration should be taken into account when examining MUTCD standards for crosswalks in school zones.

The most significant contribution of this thesis was finding that the current PHB standards in MUTCD are not transferable to the school zone context. Comparative analysis between current PHB standards and MUTCD Warrant 5 standards, which were designed specifically for school zones, led to inconsistent determinations. To deal with this inconsistency, this thesis provides analysis and a series of recommendations to translate and apply current PHB standards to school zones. These recommendations included using equivalent hourly rate of flow for pedestrians and vehicles and using guidelines designed for high-speed facilities to lower the tolerance of accepted pedestrian volumes. This latter consideration is to account for the additional safety concern required for crosswalks in school zones due to characteristics of child pedestrians. Additionally, it is recommended that when dealing with Warrant 5 or PHB standards, engineers pay particular attention to intervals where there are more pedestrians than adequate gaps if the data is available. This contrasts with current school zone standards that compare available gaps to the number of minutes in the entire study period. Using this recommended technique allows engineers to focus on the specific problem intervals as opposed to diluting the results over a full hour or longer depending on the study period length. These problem intervals arise when there are more pedestrians than available adequate gaps in traffic. The analysis and related results are promising and will help engineers make more effective and appropriate determinations with regard to applying MUTCD's Warrant 5 and PHB standards.

Another interesting finding of this thesis, based on data collected and analyzed, is associated with school policy in setting class hours. It is recommended that when determining class hours, the times associated with high pedestrian volumes ideally should not coincide with peak traffic volume hours. Intuitively high pedestrian volume periods are generally associated with school beginning and end times. This is a problem in the morning when AM rush hour typically overlaps the times that most schools begin classes. Peak traffic volumes normally encountered during AM and PM rush hours are considerably more dangerous to navigate for pedestrians than off peak hours. This is particularly true for school locations adjacent to arterials.

5.2.3. Evaluation of Crosswalk Controls

An evaluation framework has been provided in this thesis, which allows engineers to balance the considerations of pedestrian safety and motorist convenience when evaluating different design and control options for crosswalks in school zones. The evaluation was based on established guidelines provided by the HCM regarding level of service criteria for pedestrian and vehicular delay. The evaluation of pedestrian safety at different crosswalks included assessment of both pedestrian delay and motorist compliance. As a result, a level of service criteria with regard to motorist compliance was developed and used. The final outcome of this evaluation was the development and utilization of a rating system for different design and control options at school crossings. This rating system was based on LOS grades and associated ratings corresponding with motorist compliance, pedestrian delay, and motorist delay results.

The data regarding motorist compliance revealed significant levels of noncompliance (failure to yield pedestrian right of way) at marked crosswalks. On the contrary, the pedestrian signal and PHB received perfect or nearly perfect results. Pedestrian right-of-way is clearly not understood at marked crosswalk locations. This is evident by the unfazed responses by police officers as several motorists failed to yield to pedestrians at a marked crossing no more than 30 feet in front of them. Improvements in motorist compliance undoubtedly contributed to the 15% increase in pedestrian volume at Centennial Elementary School where a marked crosswalk was enhanced with the addition of a PHB. The increases in pedestrian volumes can be attributed to real or perceived gains in safety and comfort at the location with the PHB.

The pedestrian delay was perceptibly lower at marked crosswalks compared to crosswalks with signals or the PHB. The difference in pedestrian delay was insignificant between locations with a pedestrian signal compared to a location with a PHB. However, this needs to be further explored with collection of data and related analysis for more sites, before this conclusion can be generalized.

The marked crosswalk incurred the lowest amount of motorist delay of the three controls which was intuitive after evaluating the motorist compliance study. With only one half of the motorists stopping for pedestrians at marked crosswalks, motorist compliance became optional at these locations. What was surprising was the insignificant difference in motorist delay between the pedestrian signals and PHB. The similarity in motorist delay can be attributed to the significantly low percentage of correct utilization of the PHB.

The evaluations carried out in this thesis were intended to indicate the process and framework of school zone analysis as well as determine underlying issues at specific control devices. As expected, the marked crosswalks had superior motorist convenience compared to the other two control devices; however, the pedestrian safety was signifigantly comprised. As a result, it can be concluded that marked crosswalks are not an appropriate or effective control alternative at school zones. Additionally, there was little difference between pedestrian signals and the PHB. This was contrary to research results found in the aforementioned study in Lawrence, Kansas. The Lawrence study found that unwanted and unnecessary motorists delay can be reduced considerably with PHB installation when compared to traditional pedestrian signals. The evaluation in this thesis indicates that more education and awareness is needed by motorists to achieve gains of compliance as well as reductions in delay.

5.3. Recommendations

The analysis and steps developed by this thesis can be used to translate and apply current MUTCD PHB standards to the school zone context. However, for the PHB to be a serious consideration for school zone application around the country it is important to develop specific MUTCD standards for this context. Developing these standards would involve considerably more data collection at additional school zones using the PHB. Fargo currently has plans to install another PHB near Carl Ben Eielson Middle School. This provides opportunity for more data to be analyzed.

Observations related to pedestrian-vehicle conflicts at crosswalks were not collected in this study. Extensive data collection of these observations as well as calibration data from such observations would allow us to model and simulate the crosswalks in school zones and look into effectiveness of PHB timings and controls. The evaluation framework developed in the thesis can help engineers evaluate options related to design and control of crosswalks. However, it is essential that substantially more data be collected, examined, and evaluated before results can be generalized.

In conclusion, marked crosswalks are not suitable for school zones due to the inherent safety risks they pose. Public outreach and law enforcement education could increase motorist compliance at marked crosswalks by increasing awareness of current right-of-way rules. Pedestrian signals and PHBs should be the first crosswalk control consideration when designing a school zone crosswalk. There is additional potential for the PHB to improve motorist convenience which would enhance its value in crosswalk design. This enhancement can be achieved with additional informational signs and public awareness programs intended to inform and educate the public about proper PHB utilization.

5.4. Summary

In summary, this thesis was intended to determine PHB application and performance in school zones based on two objectives. The first objective was to analyze the applicability of MUTCD PHB standards and guidelines in school zones. Through recorded and analyzed data, this thesis found that current standards are inefficient in providing an applicable school zone crosswalk control. Evidence was provided when several school zone crosswalks requiring pedestrian signals were unable to satisfy more than 60% of current PHB standards requirements using the same data. The second objective was to develop a systematic framework for determining the most effective crosswalk control for maximizing pedestrian safety and motorist convenience at school zones. This thesis facilitated a comparative framework based on three of the most essential crosswalk considerations; motorist compliance, pedestrian delay, and motorist delay. This framework was carried out for three separate crosswalk control devices and found that both the pedestrian signal and PHB were ideal methods for balancing pedestrian safety and motorist convenience. The second objective also concluded that marked crosswalks are unacceptable forms of crosswalk control at school zones due to the low level of motorist compliance the device imposes.

REFERENCES

AARP. (2009). The Numerous Benefits of Walking. Retrieved December 15, 2009, from AARP.org: http://www.aarp.org/health/fitness/walking/a2004-06-17-walking-numerousbenefits.html

Baltes, M. R., & Chu, X. (2002). Pedestrian Level of Service for Midblock Street Crossings. Transportation Research Record , Volume 1818 pg. 125-133.

Bhattacharya, P., & Virkler, M. R. (2005). Optimization for Pedestrian and Vehicular Delay in a Signal Network. Transportation Research Record , Volume 1939 pg. 115-122.

Copeland, L. (2008, February 24). Cities try to improve crosswalk safety. Retrieved October 13, 2009, from USA Today: http://www.usatoday.com/news/nation/2008-02-24-crosswalk_N.htm

Dumbaugh, E., & Frank, L. (2007). Traffic Safety and Safe Routes to Schools: Synthesizing the Empirical Evidence. Transportation Research Record , Volume 2009 pg. 89-97.

FHWA. (2002). Pedestrian Facilities User Guide. McLean: Federal Highway Administration.

FHWA. (2004). A Review of Pedestrian Safety Research in the United States and Abroad. McLean: Federal Highway Administration USDOT.

FHWA. (2005[1]). Innovative Intersection Safety Improvement Strategies and Management Practices: A Domestic Scan. McLean: Federal Highway Administration.

FHWA. (2005[2]). Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations. McLean: Federal Highway Administration USDOT.

FHWA. (2009). Manual on Uniform Traffic Control Devices. McLean: Federal Highway Administration USDOT.

Fitzpatrick, K., & Park, E. S. (2009). Safety Effectiveness of HAWK Pedestrian Treatment. Transportation Research Record , Volume 2140 pg. 214-223.

FM Metro COG. (2006). 2006 Metropolitan Traffic Count Map. Retrieved November 18, 2009, from FM Metro COG: http://fmmetrocog.org/index.php?option=com_docman&task=cat_view&gid=9&Itemid=3

Foot, H. C., Thomson, J. A., Tolmie, A. K., Whelan, K. M., Morrison, S., & Sarvary, P. (2006). Children's understanding of drivers' intentions. British Journal of Development Psychology , 681-700.

Godavarthy, R. P., & Russell, D. E. (2009). Effectiveness of a HAWK Beacon Signal at Mid-Block Pedestrian Crossings in Decreasing Unnecessary Delay to the Drivers. Lawrence: Kansas State University.

Harrell, A. W., & Bereska, T. (1992). Delays in Traffic and Motorists Yielding to Pedestrians'. Perceptual and Motor Skills , 451-455.

Hatfield, J., Fernandes, R., Job, R. S., & Smith, K. (2007). Misunderstanding of right-of-way rules at various pedestrian crossing types: Observational study and survey. Accident Analysis and Prevention , 833-842.

Houten, R. V., Ellis, R., & Kim, J.-L. (2007). The Effects of Varying Minimum Green on the Percentage of Pedestrians Waiting to Cross with the WALK Signal. Transportation Research Record , Volume 2002 pg. 78-83.

Hunt, J., & Ahk, A. (1995). The Effectiveness of Pedestrian Facilities at Signal Controlled Junctions. Proceedings of the Institution of Civil Engineers-Transport , 268-277.

Ibarguen, B. (2009). Transportation Operations in Action: Safety Elements. ITE , 30-35.

IIHS. (2006). Fatality Facts 2006 - Pedestrians. Retrieved September 3, 2009, from Insurance Institute for Highway Safety: http://www.iihs.org/research/fatality_facts_2006/pedestrians.html#sec2

Isebrands, H. N., & Hallmark, S. L. (2007). School Zone Safety and Operational Problems at Exisitng Elementary Schools. Institute of Transportation Engineers , 26-31.

ITE. (1998). Design and Safety of Pedestrian Facilities. Washington D.C.: Institute of Transportation Engineers.

JAMAR Technologies Inc. (2009). Hand-Held Traffic Data Collectors. Retrieved September 5th, 2009, from JAMAR Technologies Inc.: http://www.jamartech.com/TMBs.html

Kallis, W. (2010). Safe Routes to School. US Department of Transportation: National Highway Traffic Safety Administration.

Merriam-Webster's Online Dictionary. (2009). Retrieved December 15, 2009, from Merriam-Webster's Online Dictionary: http://www.merriam-webster.com/

Microsoft. (2010). Bing. Retrieved February 9, 2010, from Bing Maps: http://www.bing.com/maps/

Mitman, M. F., & Ragland, D. R. (2007). Crosswalk Confusion: More Evidence Why Pedestrian and Driver Knowledge of the Vehicle Code Should Not Be Assumed. Transportation Research Record , Volume 2002 pg. 55-63.

NCHRP. (2006). Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Washington D.C.: National Cooperative Highway Research Program (Transportation Research Board).

NHTSA. (2007). Traffic Safety Facts: Pedestrians. Retrieved September 1, 2009, from National Highway Traffic Safety Administration: http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.dfedd570f698cabbbf30811060008a0c

PBIC. (2002). Bringing Life to Transportation Tucson Arizona DOT. Retrieved September 1, 2009, from Pedestrian and Bicycle Information Center: http://www.bicyclinginfo.org/library/details.cfm?id=2878

PBIC. (2009). walkinginfo.org. Retrieved October 13, 2009, from Pedestrian and Bicycle Information Center: http://www.walkinginfo.org/

Robertson, H. D. (1994). Manual of Transportation Engineering Studies. Institute of Transportation Engineers.

Sarkar, S., Kaschade, C., & Faria, F. d. (2003). How Well Can Child Pedestrians Estimate Potential Traffic Hazards? Transportation Research Record , Volume 1828 pg. 38-46.

Schrader, M. H. (1999). Study of Effectiveness of Selected School Zone Traffic Control Devices . Transportation Research Record , Volume 1692 pg. 24-29.

Schrank, D., & Lomax, T. (2005). 2005 Annual Urban Mobility Report. Texas Transportation Institute.

Schroeder, B. J. (2008). Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalks. Roleigh: North Carolina State University.

SRTS. (2009). National Center for Safe Routes to School. Retrieved October 15, 2009, from Saferoutesinfo.org: http://www.saferoutesinfo.org

TRB. (2000). Highway Capacity Manual. Washington D.C.: Transportation Research Board.

U.S. Centers for Disease Control and Prevention. (2005, September 30). Barriers to Children Walking to or from School: United States 2004. Retrieved March 22, 2010, from Morbidity and Mortality Weekly Report: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5438a2.htm

U.S. Department of Health and Human Services. (1996). Physical activity and health: A report of the surgeon general. Atlanata: Department of Health and Human Services.

Virkler, M. R. (1998). Pedestrian Compliance Effects on Signal Delay. Transportation Reseacrh Record , Volume 1636 pg.88-91.

APPENDIX A. MUTCD PEDESTRIAN HYBRID BEACON STANDARDS

Information taken directly from the 2009 edition of the MUTCD. To review this information further visit http://mutcd.fhwa.dot.gov/

If a traffic control signal is not justified under standard MUTCD signal warrants and if gaps in traffic are not adequate to permit pedestrians to cross, or if the speed for vehicles approaching on the major street is too high to permit pedestrians to cross, or if pedestrian delay is excessive, the need for a pedestrian hybrid beacon should be considered on the basis of an engineering study that considers major-street volumes, speeds, widths, and gaps in conjunction with pedestrian volumes, walking speeds, and delay. Once an engineering study has been conducted the following three conditions will constitute the application of a pedestrian hybrid signal.

For a major street where the posted or statutory speed limit or the 85th-percentile speed is 35 mph or less, the need for a pedestrian hybrid beacon should be considered if the engineering study finds that the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding total of all pedestrians crossing the major street for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure A.1 for the length of the crosswalk.

For a major street where the posted or statutory speed limit or the 85th-percentile speed exceeds 35 mph, the need for a pedestrian hybrid beacon should be considered if the engineering study finds that the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding total of all pedestrians crossing the major street for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure A.2 for the length of the crosswalk.

For crosswalks that have lengths other than the four that are specifically shown in Figures A.1 and A.2, the values should be interpolated between the curves.

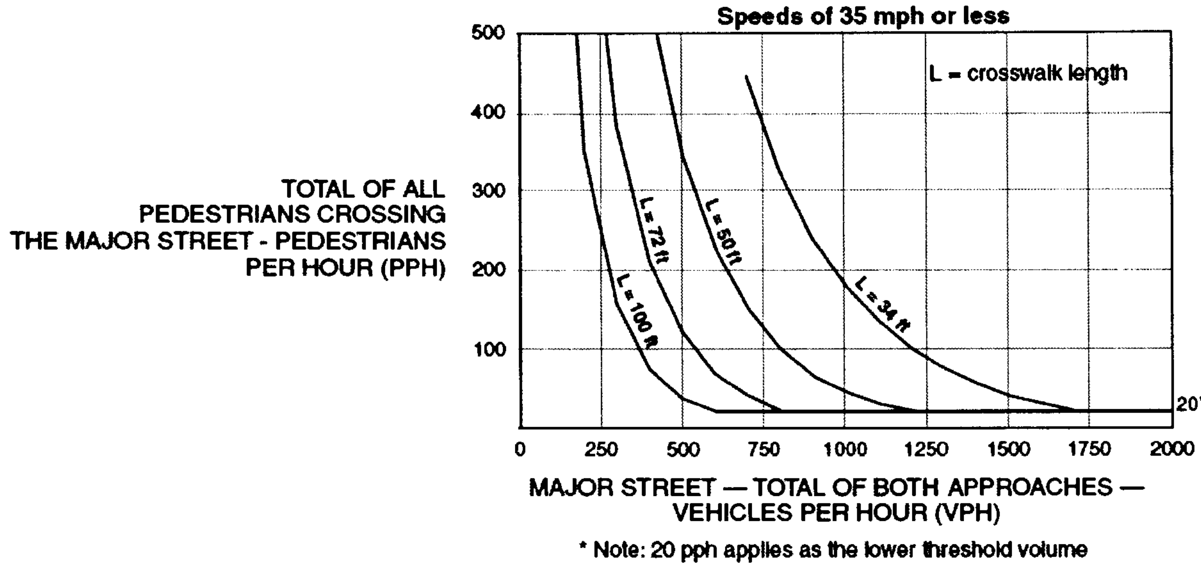


Figure A.1. Guidelines for the Installation of PHB on Low-Speed Roadways.

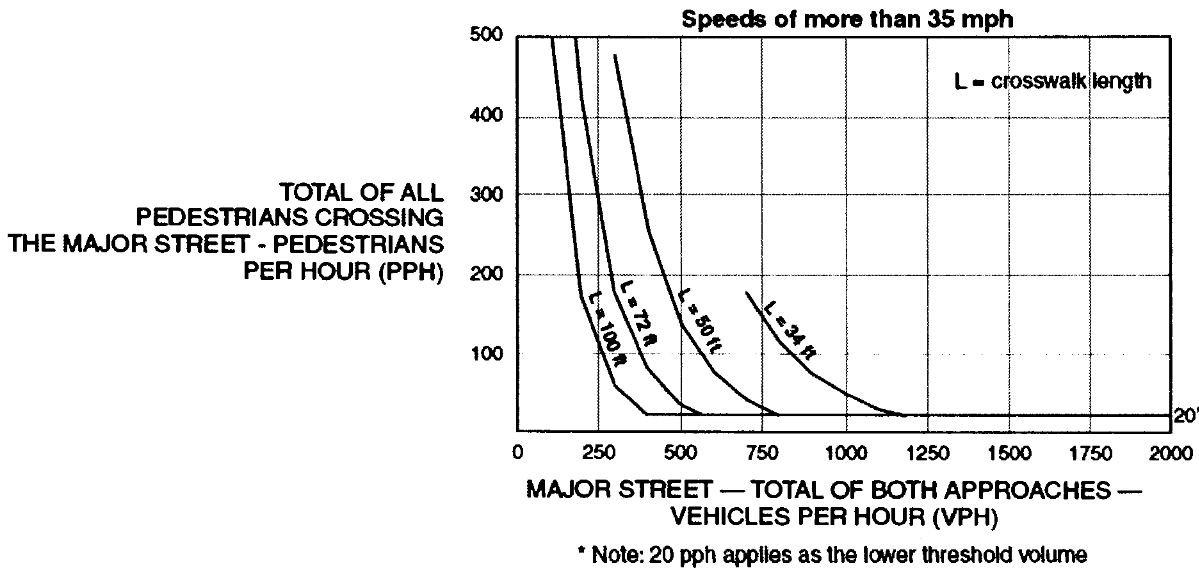


Figure A.2. Guidelines for the Installation of PHB on High-Speed Roadways.

APPENDIX B. PEDESTRIAN VOLUME STUDY RESULTS

Table B.1. AM Pedestrian Volume Results.

Interval (15-min)	Centennial Pedestrian Volume	Carl Ben Eielson Pedestrian Volume	Horace Mann Pedestrian Volume	Roosevelt Pedestrian Volume
AM-1	**2**	**3**	**2**	**5**
AM-2	**4**	**5**	**0**	**17**
AM-3	**9**	**6**	**0**	**9**
School Begins				
AM-4	**1**	**1**	**0**	**0**
Total	**16**	**15**	**2**	**31**

Table B.2. PM Pedestrian Volume Results.

Interval (15-min)	Centennial Pedestrian Volume	Carl Ben Eielson Pedestrian Volume	Horace Mann Pedestrian Volume	Roosevelt Pedestrian Volume
PM-1	**3**	**0**	**1**	**0**
School Ends				
PM-2	**20**	**11**	**4**	**9**
PM-3	**0**	**13**	**3**	**15**
PM-4	**3**	**2**	**5**	**0**
Total	**26**	**26**	**13**	**24**

APPENDIX C. VEHICLE VOLUME STUDY RESULTS

Table C.1. AM Vehicle Volume Results.

Interval (15-Min)	Centennial Major Approach (40th Ave. S)			Carl Ben Eielson Major Approach (13th Ave. S)			Horace Mann Major Approach (2nd St. N)			Roosevelt Major Approach (10th St. N)
	WB	EB	Total	WB	EB	Total	NB	SB	Total	Total
AM-1	85	181	266	62	58	120	96	95	191	246
AM-2	106	144	250	106	105	211	53	67	120	227
AM-3	95	114	209	127	146	273	57	52	109	173
School Begins										
AM-4	68	85	153	104	145	249	48	56	104	137
Total	354	524	878	399	454	853	254	270	524	783

Table C.2. PM Vehicle Volume Results.

Interval (15-Min)	Centennial Major Approach (40th Ave. S)			Carl Ben Eielson Major Approach (13th Ave. S)			Horace Mann Major Approach (2nd St. N)			Roosevelt Major Approach (10th St. N)
	WB	EB	Total	WB	EB	Total	NB	SB	Total	Total
PM-1	51	57	108	138	159	297	69	32	101	209
School Ends										
PM-2	80	57	137	154	160	314	64	50	114	252
PM-3	62	70	132	172	167	339	60	50	110	205
PM-4	83	77	160	159	159	318	62	52	114	230
Total	276	261	537	623	645	1268	255	184	439	896

APPENDIX D. GAP STUDY RESULTS

Table D.1. AM Centennial Results.

Start Time	Number of Gaps														
	2-3 sec	4-5 sec	6-7 sec	8-9 sec	10-11 sec	12-13 sec	14-15 sec	16-17 sec	18-19 sec	20-21 sec	22-23 sec	24-25 sec	26-27 sec	28-29 sec	>29 sec
7:35 AM	93	30	13	6	3	0	1	0	0	0	0	1	0	0	0
7:50 AM	85	29	9	3	1	3	0	1	0	1	0	0	0	0	1
8:05 AM	44	17	18	10	1	4	3	2	1	1	1	0	2	0	0
8:20 AM	38	14	14	6	5	7	1	3	0	3	2	0	1	0	2

Table D.2. PM Centennial Results.

Start Time	Number of Gaps														
	2-3 sec	4-5 sec	6-7 sec	8-9 sec	10-11 sec	12-13 sec	14-15 sec	16-17 sec	18-19 sec	20-21 sec	22-23 sec	24-25 sec	26-27 sec	28-29 sec	>29 sec
2:27 PM	26	11	11	12	9	9	1	1	1	3	2	0	0	1	3
2:42 PM	34	14	12	2	10	5	3	4	1	2	1	1	0	0	3
2:57 PM	37	8	10	8	5	5	5	7	0	3	2	1	2	0	0
3:12 PM	29	13	11	16	10	8	2	2	0	0	2	0	0	1	1

Table D.3. AM Carl Ben Eielson Results.

Start Time	Number of Gaps														
	2-3 sec	4-5 sec	6-7 sec	8-9 sec	10-11 sec	12-13 sec	14-15 sec	16-17 sec	18-19 sec	20-21 sec	22-23 sec	24-25 sec	26-27 sec	28-29 sec	>29 sec
7:05 AM	28	13	10	10	5	1	2	5	0	1	1	2	2	0	4
7:20 AM	49	22	9	8	8	5	3	2	0	0	2	0	0	1	0
7:35 AM	72	25	14	6	1	3	0	0	1	1	2	0	1	0	0
7:50 AM	49	25	14	6	8	5	2	1	1	0	1	0	0	0	0

Table D.4. PM Carl Ben Eielson Results.

Start Time	Number of Gaps														
	2-3 sec	4-5 sec	6-7 sec	8-9 sec	10-11 sec	12-13 sec	14-15 sec	16-17 sec	18-19 sec	20-21 sec	22-23 sec	24-25 sec	26-27 sec	28-29 sec	>29 sec
3:02 PM	55	27	9	6	5	1	1	0	1	1	1	0	0	0	0
3:17 PM	60	20	13	4	5	2	1	2	0	1	0	0	0	0	0
3:32 PM	76	17	11	9	3	1	0	2	0	0	0	0	0	0	0
3:47 PM	61	19	16	1	4	3	2	1	0	1	0	0	0	0	0

Table D.5. AM Adequate Gap Study Results.

Interval (15-min)	Centennial Number of Adequate Gaps		Carl Ben Eielson Number of Adequate Gaps	
	Gaps >= 16	Gaps > 13	Gaps >= 16	Gaps > 13
AM-1	1	2	15	17
AM-2	3	3	5	8
AM-3	7	10	5	5
School Begins				
AM-4	11	12	3	5
Total	22	27	28	35

Table D.6. PM Adequate Gap Study Results.

Interval (15-min)	Centennial Number of Adequate Gaps		Carl Ben Eielson Number of Adequate Gaps	
	Gaps >= 16	Gaps > 13	Gaps >= 16	Gaps > 13
PM-1	11	12	3	4
School Ends				
PM-2	12	15	3	4
PM-3	15	20	2	2
PM-4	6	8	2	4
Total	44	55	10	14

APPENDIX E. MOTORISTS COMPLIANCE STUDY RESULTS

Table E.1. AM Motorist Compliance Results

Interval	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage
AM-1	**3**	**5**	**62.5%**	**0**	**34**	**100.0%**	**0**	**19**	**100.0%**
AM-2	**10**	**15**	**60.0%**	**0**	**36**	**100.0%**	**0**	**16**	**100.0%**
AM-3	**5**	**17**	**77.3%**	**0**	**12**	**100.0%**	**1**	**13**	**92.9%**
School Begins									
AM-4	**14**	**8**	**36.4%**	**0**	**0**	**0.0%**	**0**	**0**	**0.0%**

Table E.2. PM Motorist Compliance Results

Interval	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage	Non-compliant Vehicles	Compliant Vehicles	Compliancy Percentage
PM-1	**6**	**2**	**25.0%**	**0**	**0**	**0.0%**	**0**	**4**	**100.0%**
School Ends									
PM-2	**22**	**25**	**53.2%**	**0**	**43**	**100.0%**	**0**	**45**	**100.0%**
PM-3	**0**	**0**	**0.0%**	**0**	**13**	**100.0%**	**0**	**2**	**100.0%**
PM-4	**2**	**0**	**0.0%**	**0**	**4**	**100.0%**	**0**	**2**	**100.0%**

APPENDIX F. PEDESTRIAN DELAY STUDY RESULTS

Table F.1. AM Pedestrian Delay Results

	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
Interval	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)
AM-1	2	4.75	2.38	7	39.00	5.57	2	0.00	0.00
AM-2	4	24.25	6.06	17	124.50	7.32	4	0.00	0.00
AM-3	9	34.25	3.81	9	0.00	0.00	2	35.00	17.50
School Begins									
AM-4	1	34.50	8.63	0	0.00	0.00	0	0.00	0.00

Table F.2. PM Pedestrian Delay Results

	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
Interval	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)	Number of Pedestrians	Total Delay (sec)	Average Delay (sec/ped)
PM-1	3	19.75	6.58	1	18.75	18.75	1	0.00	0.00
School Ends									
PM-2	20	106.25	5.31	13	392.00	30.15	28	530.20	18.94
PM-3	0	0.00	0.00	18	235.25	13.07	5	0.00	0.00
PM-4	3	15.00	5.00	5	100.00	20.00	4	0.00	0.00

APPENDIX G. MOTORISTS DELAY STUDY RESULTS

Table G.1. AM Motorist Delay Results.

	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
Interval	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)
AM-1	8	21	2.63	34	696	20.47	19	405	21.32
AM-2	31	105	3.39	36	706	19.61	16	258	16.13
AM-3	23	65	2.83	12	198	16.50	14	234	16.71
School Begins									
AM-4	12	30	2.50	0	0	0.00	0	0	0.00

Table G.2. PM Motorist Delay Results

	Marked Crosswalk - Centennial			Pedestrian Signal - Combined			PHB - Centennial		
Interval	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)	Number of Vehicles	Total Delay (sec)	Average Delay (sec/veh)
PM-1	9	14	1.56	0	0	0.00	4	63	15.75
School Ends									
PM-2	46	49	1.07	43	899	20.91	45	831	18.47
PM-3	0	0	0.00	13	248	19.08	2	27	13.50
PM-4	2	0	0.00	4	78	19.50	2	23	11.50