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EVALUATION OF PEDESTRIAN CROSSWALKS IN AN URBAN ENVIRONMENT

By

Darcin Akin

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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Department of Civil and Environmental Engineering

2000

EVALUATION OF

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ABSTRACT

EVALUATION OF PEDESTRIAN CROSSWALKS IN AN URBAN ENVIRONMENT

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This study assesses pedestrian crossing options from the perspectives of crosswalk operations, pedestrian perceptions and preferences, and pedestrian safety. Operational analyses assisted in the determination of the effectiveness of pedestrian crossing options through the estimation of pedestrian crossing compliance rate, crossing time, level of service, and pedestrian conflicts with turning vehicles at signalized intersections. The study of pedestrian perceptions and preferences was based on a user's survey that was developed and distributed to potential users crossing a divided urban boulevard. Finally, in the safety analysis, pedestrian related crashes were reviewed and summarized for the study corridor. Moreover, historical crash data from the state of Michigan were reviewed in order to evaluate the relative safety of various crossing locations. The study site used in this research was a 1 km (0.63 mi) long divided boulevard section of Grand River Avenue (M-43) between Abbott and Bogue Streets in downtown East Lansing, Michigan. The AADT was approximately 32,000 vehicles per day in both directions.

The results from the crossing compliance analysis indicate that a strong correlation exists between the presence of a positive type of traffic control and pedestrian spatial crossing compliance rate. The highest spatial crossing

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compliance was observed at the signalized intersection crosswalks (83.13%). However, the overall crossing compliance rate (i.e., compliance with both crosswalk location and pedestrian WALK signal indication) at the signalized crosswalks was very low (42.98%) compared to the observed spatial compliance. This indicates that a majority of pedestrians in the study site do not comply with the "DONT WALK" signal indication. The analysis of pedestrian crossing times at the signalized intersection crosswalks allowed the evaluation of the level of service of pedestrian crossings on the basis of average space per pedestrian. The analysis indicated that existing methodologies overestimated the pedestrian crossing times, thus refinements of such methodologies are recommended to account for the actual conditions in the study corridor. In the conflict study, interactions of pedestrians with right- and left- turning vehicles sharing the same green interval were examined and modeled using regression analysis techniques. The models yielded very satisfactory results. The analysis of the survey responses led to conclusions regarding the acceptability of various pedestrian crossing facilities and treatments by users, and provided important insights into the attitudes and preferences of pedestrians using the study site. The results from the survey analysis support the notion that properly marked pedestrian crossing facilities encourage users to cross at designated crossing locations. Among the various crossing options studied, pedestrian users at the study site perceived the marked midblock crosswalks the most favorable.

The crash data at the study site was limited. Thus statistical comparisons were avoided and a detailed investigation was recommended for future research.

To my beloved wife, *Vah*
big-time supporters mc
beloved princ

To my beloved wife, *Vahide*; my loving mom and dad, *Sadiye* and *Mehmet*; my big-time supporters mother- and father-in-law, *Ayfer* and *Mustafa*; and my beloved princess and prince, *Busra Zeynep* and Y*avuz*.

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continuous support, advic

Michigan State University

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future academic life.

My appreciation ar

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Last but not least, I

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mother of my two beloved

I also would like to

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supported my five years of

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I would like to express my sincere gratitude and appreciation to my advisor and all-time supporter Dr. Virginia P. Sisiopiku for her invaluable continuous support, advice and guidance throughout my doctoral education at Michigan State University (MSU). My experience with Dr. Sisiopiku will never be forgotten and will always be remembered as an invaluable experience in my future academic life.

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Last but not least, I would like to express my love and appreciation to my wife, Vahide. Without her love, patience, and constant support as a wife and mother of my two beloved children, I could not have finished this endeavor.

I also would like to thank the Michigan Department of Transportation for financially supporting the data collection and analysis of this study. Finally, I would like to express my love to my country, Turkey, and its people; and my gratitude to the Higher Education Council of Turkey (YOK) and GIT, which supported my five years of stay in the U.S. to pursue my doctoral education.

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ADVT: Average daily v
crosswalk per

ADPT: Average daily p
entering a cros

ANOVA: Analysis of var

CA: Crosswalk area

CBD: Central busines

CI: Confidence inte

CIA: Crosswalk influ

D: Pedestrian initia

DW: Pedestrian red

df: Degree of freed

FARS: Fatality analysi
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involve a fatal

G: Walk interval (

HCM: Highway Capa
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Transportation

ITE: Institute of Tra

L: Pedestrian cro

L_{cw}: Length of cros

LOS: Level of servic
levels of traffic
paths, etc.)

LIST OF ABBREVIATIONS and NOTATIONS

AADT: Annual average daily traffic (vehicle/day, pedestrian/day).

ADVT: Average daily vehicular traffic (average number of vehicles entering a crosswalk per day).

ADPT: Average daily pedestrian traffic (average number of pedestrians entering a crosswalk per day).

ANOVA: Analysis of variance.

CA: Crosswalk area (see Figure 3.3 for definition).

CBD: Central business district.

CI: Confidence interval.

CIA: Crosswalk influence area (see Figure 3.2 for definition).

D: Pedestrian initial start-up delay (sec).

DW: Pedestrian red (DON'T WALK) interval (sec).

df : Degree of freedom.

FARS: Fatality analysis reporting system. FARS contains data on all vehicle crashes in the United States that occur on a public roadway and involve a fatality in the crash.

G: Walk interval (sec) (see Figure 4.1 for definition).

HCM: Highway Capacity Manual. In this text, *HCM*, is used for the 1997 US Highway Capacity Manual, Special Report 209, published by Transportation Research Board.

ITE: Institute of Transportation Engineers.

L: Pedestrian crossing distance (m).

L_{CIA}: Length of crosswalk influence area (m).

LOS: Level of service. LOS denotes quantitative, qualitative, or both service levels of traffic facilities (highways, crosswalks, pedestrian and bicycle paths, etc.)

LS: Late starters a
pedestrian clea
up completing

LTVPC: Number of left-
intersection cr

LTW: Left-turning ve

M_c: Average space

MMCW: Marked midblo

M_s: Average space
(m^2/ped).

MUTCD: The Manual on

N: Number of wa
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NSMCW: Non-striped m
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OCCR: Overall crossi
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P: Number of re

PCCR: Pedestrian cr
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pedestrian cr

PC: Potential conf
of pedestrians

PCA: Potential conf
conflicts with

PCR: Pedestrian cr
pedestrians).

P_x: Total number
crosswalk.

LS: Late starters are the pedestrians who start to cross during the pedestrian clearance interval (flashing DON'T WALK signal) and end up completing their crossing usually during pedestrian red interval.

LTVPC: Number of left-turning vehicle-pedestrian conflicts in signalized intersection crosswalks (conflicts/hr).

LTVV: Left-turning vehicle volume at signalized intersections (veh/hr)

M_C: Average space per pedestrian in crosswalks (m^2/ped).

MMCW: Marked midblock crosswalks.

M_S: Average space per pedestrian for the maximum surge condition (m^2/ped).

MUTCD: The Manual on Uniform Traffic Control Devices.

N: Number of walkers in a platoon of pedestrians crossing together during a signal interval.

NSMCW: Non-striped midblock crosswalks. There are two of this kind of midblock crosswalks in the study site. They do not have stripes (markings) on the pavement, and the curbs and median are not cut for easy access for bicyclists and pedestrians in wheelchair.

OCCR: Overall crossing compliance rate. Percentage of pedestrians who simultaneously comply with the location and the signal of a pedestrian crosswalk. This definition envelops spatial and temporal compliances (see Equation 3.4 for formulation).

P: Number of reported pedestrian-vehicle crashes per year.

PCCR: Pedestrian crossing compliance rate (%), i.e., percentage of pedestrians who comply with the location and the signal (if any) of a pedestrian crosswalk.

PC: Potential conflict. Defined as the number of potential conflict situations of pedestrians with turning vehicles sharing the same green interval.

PCA: Potential conflict area. Defined in Figures 5.1 and 2 for pedestrian conflicts with turning vehicles at signalized intersections.

PCR: Pedestrian crash rate (pedestrian accidents per million vehicles and/or pedestrians).

P_{CA}: Total number of pedestrians (per hour) in the crosswalk area (CA) of a crosswalk.

P_{DW}: Total number c
crosswalk (pec

P_C: Number of pec
(ped/hr).

P_{CT}: Number of pec
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P_T: Number of pede
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PV: Pedestrian volu

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RTV: Right-turning ve

RU: Regular users
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S: Sneakers (peds
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SCOR: Spatial crossin
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SCW: Signalized inte

Sig: Significance.

P_{CIA}: Total number of pedestrians in the crosswalk influence area (CIA) of a crosswalk (ped/hr).

P_L: Number of pedestrians who cross within the crosswalk area, CA, (ped/hr).

P_{LT}: Number of pedestrians who comply with both crossing location and pedestrian WALK signal indication (ped/hr).

PS(VR): Partial sneakers (vehicles running) are pedestrians crossing during the DON'T WALK signal while vehicles are passing by at signalized intersections. These are risk takers. Pedestrians classified as *PS(VR)* cross a portion of the roadway during pedestrian DON'T WALK signal indication while vehicles in both directions are in motion, and complete their crossing (from the median to the opposite curbside) usually during pedestrian WALK signal indication.

PS(VS): Partial sneakers (vehicles stopped). This definition is applied to pedestrian classifications at signalized intersections under lead/lag left-turn vehicle phasing only. Pedestrians classified as *PS(VS)* cross from a curbside to the median during the DON'T WALK signal indication while vehicles in this direction are stopped, and complete their crossing (from the median to the opposite curbside) during pedestrian WALK signal indication.

P_T: Number of pedestrians who comply with the WALK signal indication (ped/hr).

PV: Pedestrian volume in crosswalks (ped/hr).

RTVPC: Number of right turning vehicle-pedestrian conflicts in signalized intersection crosswalks (conflicts/hr).

RTVV: Right-turning vehicle volume in signalized intersections (veh/hr).

RU: Regular users (pedestrians who start crossing during the WALK signal and complete crossing before the signal turns to DON'T WALK).

S: Sneakers (pedestrians cross the entire length of the street during the DON'T WALK signal).

SCCR: Spatial crossing compliance rate (%). Percentage of pedestrians in CIA who comply with the crosswalks location, start and complete crossing within the crosswalk area (see Equation 3.2 for formulation).

SICW: Signalized intersection crosswalks.

Sig: Significance.

T: Pedestrian cro

TCCR: Temporal cros
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crossing durir
DON'T WALK

TS: Crosswalk tim
(m^2-sec/cycle

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TV: Turning vehicl

u: Pedestrian cro

USICW: Unsignalized ir

TWLT: Two-way left-t

V: Total incoming
(ped/cycle).

V_m: Maximum num

VV: Two-way vehic

W: Crosswalk widt

x: Average pedes
width).

T: Pedestrian crossing time (sec).

TCCR: Temporal crossing compliance rate (%). Percentage of pedestrians in CA who comply with the pedestrian WALK signal indication, start crossing during the WALK signal and complete before the steady DON'T WALK signal (see Equation 3.3 for formulation).

TS: Crosswalk time-space available to pedestrians during one cycle length (m^2-sec/cycle).

TVPC: Number of turning vehicle-pedestrian conflicts (conflicts/hr).

TVV: Turning vehicle volume in signalized intersections (veh/hr),

u: Pedestrian crossing speed (m/sec).

USICW: Unsignalized intersection crosswalks.

TWLT: Two-way left-turn.

V: Total incoming and outgoing pedestrians volume in a crosswalk (ped/cycle).

V_m: Maximum number of pedestrians in a crosswalk.

VV: Two-way vehicular volume on a stretch of a road (veh/hr).

W: Crosswalk width (m).

x: Average pedestrian headway in a crosswalk (sec/ped/m of crosswalk width).

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Chapter 1

INTRODUCTION

Crosswalks serve the crossing needs of pedestrians and separate them from vehicular traffic in high volume urban corridors. The availability of pedestrian crosswalks, especially in urbanized areas, is vital for pedestrian activities. Crosswalks need to be safe and convenient, and provide an acceptable level of service to the users in the competitive urban environment. The separation of pedestrians from vehicular traffic and the provision of acceptable level of service in the crosswalks are expected to increase pedestrian crossing compliance and safety.

Traffic engineers and transportation planners are always desirous of gaining insight into the compliance of pedestrian crossing at locations with various crosswalk designs and pedestrian treatments. Information obtained from the analysis of pedestrians' preferences, behaviors and attitudes can be used as a guide for future pedestrian planning projects through the identification of treatments that are favored by pedestrians. This study presents results from the evaluation of various types of pedestrian crosswalks and their features in an urban environment. Pedestrian crossing options are assessed with respect to crosswalk operations, pedestrian perceptions and preferences, and pedestrian safety in urban crosswalks.

1.1. Site Description

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1.1. Site Description

Data used in this study were collected on a section of Grand River Avenue in downtown East Lansing, Michigan. Grand River Avenue is an east-west corridor at the north boundary of Michigan State University (MSU) campus and the central business district (CBD) of the city of East Lansing. The selected section is a 1-km (0.63-mi.) long divided boulevard between Abbott and Bogue Streets. The annual average daily traffic (AADT) is approximately 32,000 vehicles. The site map is presented in Figure 1.1. The study section is the part of Grand River Avenue highlighted on the map. This section was renovated from 1994 through 1995 to include well-marked pedestrian crosswalks, midblock crosswalks, pedestrian signs and shelters at the median, brick paving at crosswalk medians and curbs, and physical barriers). With the new crosswalk layouts, conflicts between pedestrians and left-turning vehicles turning from Grand River Avenue onto cross streets are reduced by locating the crosswalks at only the east side of the intersections. The Collingwood Street intersection was the only one that maintained crosswalks on both sides of the intersection. The signalization work aimed at improving signal timing and phasing schemes was completed in 1996.

The corridor has four signalized intersections, two of which are cross-intersections, and the other two are T-intersections without a south leg. One of the cross-intersections has crosswalks on both sides of the intersection, and the others have only one on the east side of the intersection. In addition, there are two unsignalized intersections that have a crosswalk on only one side of the ntersection. Both un

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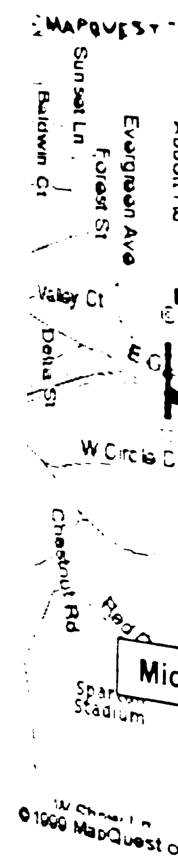

intersection. Both unsignalized intersections are T-type intersections without a south leg. Furthermore, four marked midblock crosswalks are located in the study corridor, two of which have shelters at the median (shelters are kiosk type of physical structures located on the median). Finally, there are two non-striped midblock crosswalks, which have a paved median, but no crosswalk stripes on the pavement and they also have no curb cuts designed to allow easy access for pedestrians with wheelchair and bicyclists.

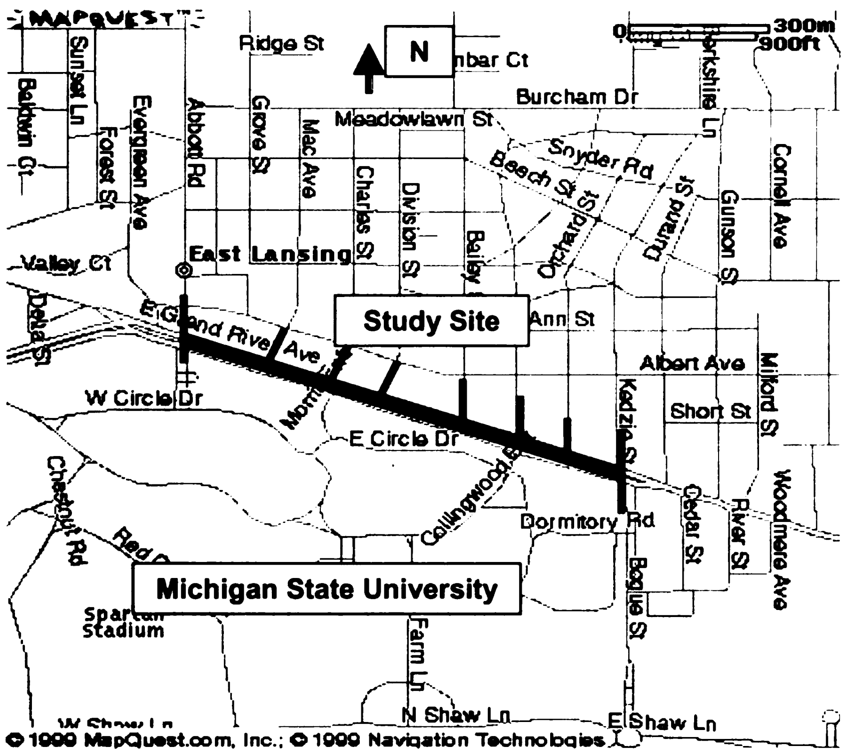

Figure 1.1. Site map

1.2. Study Description

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1.2. Study Description

In this study, pedestrian crosswalks in an urban environment were evaluated from the perspectives of crosswalk operations, pedestrian perceptions and preferences, and pedestrian safety. Operational analyses performed included the study of pedestrian crossing compliance with all types of crosswalks, pedestrian crossing time and crosswalk level of service, and pedestrian conflicts with turning vehicles sharing the same green interval with pedestrians at the signalized intersection crosswalks in the study site.

The data used in the operational analyses were collected by direct observation of pedestrian movements using video cameras. Pedestrian crosswalks and other features were evaluated based on pedestrian crossing compliance. Pedestrian crossing times and turning-vehicle pedestrian conflict data were used to evaluate pedestrian signal timings and signal phasing.

Pedestrian perception and preference data were collected through a survey distributed electronically to potential users of the study site. Responses from "frequent users" were used to determine pedestrian perceptions and preferences toward various pedestrian facilities available in the study site

To gain an insight on pedestrian safety, historical crash data for the years 1988 to 1998 were reviewed and analyzed. In addition, pedestrian crash data for the entire state of Michigan over a 5-year period (1994-1998) were reviewed. The data were stratified by type of crossing location in order to determine the relative safety of pedestrian crossing options (signalized, unsignalized, and midblock crossing locations).

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1.3. Scope, Purpose and Objectives of the Study

The scope of this study covers the analysis of pedestrian compliance toward the use of signalized intersection and unsignalized intersection, marked and non-striped midblock crosswalks. Moreover, the effect of other pedestrian crossing related treatments on pedestrian crossing compliance was considered. Such treatments included pedestrian signals, signs, and median shelters at midblock crosswalk locations.

The purpose of the study is to assess pedestrian crosswalks in an urban environment. In order to meet the purpose, the following objectives were identified and addressed:

1. determine pedestrian crossing compliance for various types of crosswalks in the study site;
2. determine pedestrian levels of service at signalized intersection crosswalks, and test the appropriateness of pedestrian signal timing settings based on measured pedestrian crossing times;
3. examine and model interactions between turning vehicles and pedestrians at signalized intersection crosswalks based on potential turning vehicle-pedestrian conflicts;
4. analyze pedestrians' preferences and perceptions toward various pedestrian treatments in the study area by collecting data via a user's survey; and

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5. evaluate the relative safety of the various types of pedestrian crossing locations based upon site specific and statewide pedestrian crash data.

In achieving objectives 1 through 3, pedestrian movement data collected along the study site using video cameras were utilized. By direct observation of pedestrian movements, it was possible to determine where pedestrians crossed and which settings were favored by the users. Accomplishment of these objectives provides an insight on pedestrian crossing compliance and ways to improve it. Especially the achievement of objective 3 can be used to identify problematic locations in terms of pedestrian-turning vehicle conflicts, i.e., the locations that impose a relatively high risk to pedestrians sharing the same green interval with turning vehicles and that may need improvements. Furthermore, the assessment of the various pedestrian treatments will pinpoint the solutions that have a good potential to increase pedestrian crossing compliance when implemented in other locations with similar geometric, traffic and user characteristics.

Conclusions to be drawn from the analysis of objectives 2 and 3 can enhance the current understanding of theories and practices used to accommodate pedestrian needs and can suggest ways to improve them. Moreover, the analyses related to objective 2 will provide means for the estimation of pedestrian level of service at signalized intersections and the assessment of the effectiveness of signal settings to meet minimum pedestrian crossing requirements. The achievement of objective 4 will identify preferences and perceptions of pe

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and perceptions of pedestrian users toward the various crossing options and pedestrian treatments. Finally, objective 5 will provide an insight on pedestrian safety at the various crossing locations.

This document is organized in chapters following the study objectives. In chapter 2, a literature review is presented with respect to the objectives described above. Objectives 1 through 3 are addressed in chapters 3, 4 and 5. Objectives 4 and 5 are presented in chapters 6 and 7, respectively. Summary of all the chapters and main conclusions is offered in chapter 8.

1.4. Contributions of the Research to the State of the Art

Existing pedestrian crossing options were evaluated from three perspectives: 1. operational analysis, 2. pedestrian preference and perception study, and 3. pedestrian safety analysis. The following contributions to the state of the art are to be made by this study:

- In operational analysis of crosswalks, the calculation of "pedestrian crossing compliance" is clearly formulated and defined for common types of crosswalks in terms of percent of pedestrians who comply with the crossing location and/or pedestrian signal indications. Furthermore, pedestrian crossing compliance is categorized and analyzed as spatial, temporal and overall compliance.
- The term of "crosswalk influence area (CIA)" is introduced and clearly defined for pedestrian crosswalks.

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- Existing methods to estimate pedestrian crossing time are tested against field data. Suggestions are made on how to improve existing equations to better reflect actual conditions;
- A new terminology, potential conflict (PC), is introduced and defined, related to pedestrian conflicts sharing the same green interval with turning vehicles. A potential conflict area (PCA) is defined in pedestrian crosswalks. The estimation of PCs between the left- and right-turn vehicles and pedestrians was explored and modeled using statistical techniques. The linear regression models proposed examined the relationship between pedestrian and turning-vehicle volumes, and PCs.
- Pedestrians' preferences and perceptions toward various crossing facilities and treatments are analyzed in order to obtain information on types of facilities that pedestrians prefer, crossing location and timing, and pedestrians' perceptions toward the safety and efficiency of the existing facilities. Through the survey analysis, pedestrian users are given an opportunity to identify favorable crossing facilities and treatments for themselves.

2.1. Introduction

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Chapter 2

LITERATURE REVIEW

2.1. Introduction

A literature review was conducted to develop a good understanding of how similar problems were approached in the past and the type of techniques were used previously in order to evaluate pedestrian crosswalks. The literature review is divided into three broad categories, in agreement with the subjects of the research study: 1. operational study of pedestrian crosswalks, 2. pedestrian preference and perception study, and 3. safety study of pedestrian crosswalks.

The literature review on operational analysis of crosswalks is divided into five parts: a. pedestrian compliance and behavior, b. pedestrian level of service and crossing time, c. pedestrian walking speed and start-up time, d. turning vehicle-pedestrian conflicts and accidents, and e. pedestrian signs, signals and alternative signal schemes. Following this section, previous research findings related to pedestrian perceptions and preferences are summarized. In the final section, literature related to the safety of pedestrian crosswalks is reviewed and summarized.

2.2. Operational Studies of Pedestrian Crosswalks

The review of operational studies of crosswalks included pedestrian compliance and behavior in crosswalks. The reviews of pedestrian level of service and crossing times at signalized crosswalks, pedestrian walking speed and start-up time.

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and start-up time, turning vehicle-pedestrian conflicts and accidents, and pedestrian signs and signals are also included in this section.

2.2.1. Pedestrian Crossing Compliance and Behavior

Pedestrian movements are less predictable than vehicular movements due to the lack of enforcement of pedestrian regulations, the flexibility of choosing walking paths, and higher maneuver capability of pedestrians compared to motor vehicles. Moreover, pedestrians often do not consider themselves to be required to comply with traffic laws and regulations as much as motorists do (Gailitis, 1995). Probably this is the reason why pedestrian compliance with traffic signals is low in many cities as reported in an early study by Orne (Orne, 1959).

2.2.1.1. Definition of "Pedestrian Crossing Compliance"

Pedestrian crossing compliance can be defined as the legal pedestrian crossing of a roadway, i.e., in compliance with pedestrian WALK signal indication and the location of the crosswalk. Crossing compliance in pedestrian crosswalks can be categorized as "compliance with location or spatial crossing compliance," "compliance with signal or temporal crossing compliance," and "compliance with both location and signal or overall crossing compliance." The compliance with location yields the percentage of pedestrians who cross legally with respect to the location of crosswalks. Temporal compliance refers to the pedestrian compliance rate with respect to the pedestrian WALK signal indication in signalized crosswalks. Temporal compliance rate is an indicator of whether signal timing and phas

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signal timing and phasing scheme are properly designed for pedestrians. Overall compliance considers both spatial and temporal compliances and applies to signalized crosswalks (Sisiopiku and Akin, 1999:2). Rouphail (1984) defined pedestrian crossing compliance rates at signalized and unsignalized midblock crosswalks in a similar way.

At signalized intersections many pedestrians tend not to comply with pedestrian WALK signal indication, especially at low vehicular traffic flow levels. If one is interested only in the assessment of the attractiveness of signalized crosswalks, relative to unsignalized intersection or midblock crosswalks, spatial crossing compliance should be used as a measure of effectiveness (Sisiopiku and Akin, 1999:2). By doing so, the crossing compliance with pedestrian WALK signal indication is excluded from study results. Therefore, design problems with signal timing and phasing do not conceal the real attractiveness of signalized crosswalks. Also, signal timing and phasing changes can be done very easily. Signal compliance is totally related to signal design (signal timing and phasing plans), vehicular traffic conditions (gap, arrival type, speed, etc.), and pedestrian attitudes. Spatial crossing compliance is a very important measure of effectiveness, which indicates whether or not the location of the crosswalk is selected appropriately relative to pedestrian paths, trip origins and destinations, and whether or not the crosswalk is well marked, safe and convenient.

Tanaboriboon and Jing (1994) studied walking activities and the characteristics of Beijing pedestrians. They defined illegal crossing as "crossing a road during the red signal." Basically they used temporal crossing compliance as a measure of effec

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a measure of effectiveness. However, if one really would like to know how efficient signalized intersection crosswalks are overall, "overall crossing compliance" should be the criterion used since both spatial and temporal compliance are important at signalized crosswalks.

2.2.1.2. Crossing Compliance in Pedestrian Crosswalks

Tanaboriboon and Jing (1994) reported that the pedestrian crossing compliance with the pedestrian signal indication were 70 and 57 percent at two study locations. The authors presented the impatience of pedestrians and the lack of effective enforcement as the main reasons for the low compliance with respect to pedestrian signals. The former reason contradicts Tanaboriboon's other studies in which he reports that Asian pedestrians walk at slower pace compared to their Western counterparts (Tanaboriboon, 1986, and Tanaboriboon and Guyano, 1991).

Enforcement on pedestrians is an unpopular practice due to not only the expense associated with it but also civilians are opposed to heavy police presence on streets. Alternatively, attractive and efficient designs of pedestrian facilities could encourage proper channelization of pedestrian traffic and result in a possible increase in crossing compliance. Another method to increase crossing compliance involves educational programs targeting pedestrian adults and school-age children. Special emphasis should be placed on issues of drunk pedestrians and the elderly.

Rouphail (1984) revealed that pedestrian crossing compliance rates at signalized and unsignalized midblock crosswalks were 85.4, and 86.4 with

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pedestrian sign respectively (84.2 without pedestrian sign). The compliance rates reported in the literature confirm that pedestrian compliance varies from location to location, city to city, and environment to environment. Also, crosswalk features, pedestrian characteristics, preferences and habits are expected to affect compliance rates. Therefore, the comparison of crossing compliance rates from one study to another is not very meaningful without knowing pedestrian characteristics and behaviors, vehicular traffic conditions, and the location of crosswalks relative to major pedestrian paths leading to crosswalks. When possible, various crossing options should be evaluated in a same environment. This approach is preferred for more meaningful comparisons since the effects of pedestrian characteristics, traffic exposure and geometric features can be isolated from the effect of crosswalk features. Moreover, pedestrian behavior and attitudes are very important determinants in crossing compliance. It is important to know what types of facilities pedestrians favor and what the attitudes of pedestrians toward pedestrian facilities are.

2.2.1.3. Pedestrian Behaviors and Attitudes

A study by Forsythe and Berger (1973) presented the results of interviews with pedestrians crossing unsafely during DON'T WALK signal indication or pedestrian red interval. It was reported that the reason for unsafe crossing was mainly time-related. A need to hurry or a desire to keep moving was the main reason behind the lack of compliance with pedestrian signals.

Tanaboriboon and Jing (1994) reported that pedestrians in Beijing were less enthusiastic about using overpasses and underpasses than signalized crosswalks. Howe

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crosswalks. However, when the safety aspects and other related attributes were appraised, pedestrians did not favor any type of crossing in particular. The authors concluded that pedestrians in Beijing would accept any type of crossing facility as long as they were appropriate and sufficient. However, one should be cautious when applying conclusions from the behavioral studies conducted abroad to U.S. conditions since the pedestrian behaviors might be very different due to differences in socioeconomic characteristics of the study populations.

To encourage crossing compliance, pedestrian facilities should be convenient and safe for crossing and walking activities. Comfort, security and economy of the walking environment are environmental factors that contribute to the walking experience, and therefore to perceived level of service (*Highway Capacity Manual*, 1997*)*. Convenience refers to easiness to access the facility, availability of pathways leading to crosswalks, grades, ramps at curbs and medians, ability to perform a meaningful walking speed, and lack of obstructions on the facility. Level of service is used as an indicator of the quality of the walking facilities although it is calculated using only quantitative measures (crossing speed and time, and volume) as described in the 1997 *Highway Capacity Manual*.

2.2.2. Pedestrian Level of Service and Crossing Time at Signalized Crosswalks

Pedestrians crossing times are used in the determination of pedestrian level of service (LOS) at signalized crosswalks. Pedestrian crossing times also have to be estimated properly in order to design pedestrian signal timing in a safe and efficient way

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safe and efficient way. If the pedestrian WALK interval is inadequate, pedestrians may not be able to complete their crossing during the designated time interval (green plus flashing red) and their safety may be compromised. On the other hand, if pedestrian green time is excessively allocated, then unnecessary delays are experienced by vehicles. Pedestrian safety depends on well-designed signal phasing schemes with appropriate crossing times designated for pedestrians. At locations where the pedestrian demand is high, pedestrians should be separated from turning vehicles through the allocation of exclusive pedestrian WALK interval. Turning vehicle restrictions must be seriously considered at locations where crosswalk analysis shows low pedestrian level of service (*Highway Capacity Manual*, 1997).

2.2.2.1. Pedestrian Level of Service (LOS) at Signalized Crosswalks

Pedestrian level of service (LOS) can be defined as quantitative as well as qualitative. The following sections will describe both.

2.2.2.1.1. Quantitative LOS of Pedestrian Facilities

The main measure of effectiveness used in the U.S. to define pedestrian level of service (LOS) at signalized crosswalks is the average pedestrian space (*Highway Capacity Manual*, 1997). This is a function of pedestrian crossing time and other parameters including crosswalk width, pedestrian crossing length, pedestrian volumes, length of pedestrian green signal indication, and behavioral characteristics.

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The "Pedestrians" chapter of the 1997 *Highway Capacity Manual* (Chapter 13) uses the average space per pedestrian criterion for pedestrian crosswalk level of service estimation. The average space per pedestrian, M_c, is defined as

$$M_c = TS/(V * T) \quad \text{Eq.2.1}$$

where

M_c = average space per pedestrian (m^2/ped);

TS= crosswalk time-space available to pedestrians during one cycle length (m^2-sec/cycle);

V = total incoming and outgoing pedestrians volume (ped/cycle), and

T = pedestrian crossing time (sec).

The crosswalk time-space, TS, available to pedestrians is calculated as

$$TS = W * L * G \quad \text{Eq.2.2}$$

where

W = crosswalk width (m),

L = pedestrian crossing distance (m),

G = walk interval (sec), and other variables as previously defined.

The walk interval, G, is typically the sum of the pedestrian green and flashing red intervals reduced by 3 sec to account for start up delays due to pedestrian perception-reaction. A two-dimensional time-space diagram illustrating the approach described above is shown in Figure 2.1.

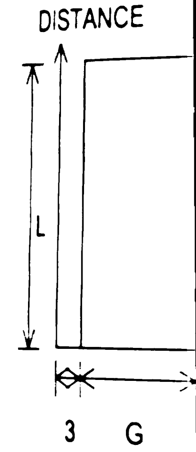

Figure 2.1. Time-spac

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Table 2.1. Pedestrian

Level of service
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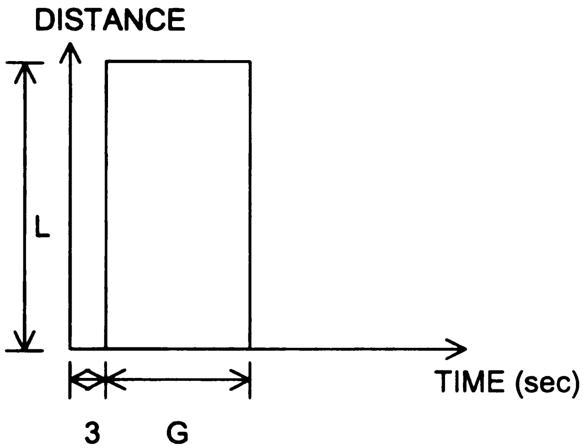

Figure 2.1. Time-space diagram for HCM approach (Virkler, 1995)

If pedestrian crossing volumes and the required pedestrian crossing time are known, then the crosswalk level of service can be determined. The relationship between the average pedestrian space (m^2/ped) and LOS is shown in Table 2.1.

Table 2.1. Pedestrian level of service on walkways (*1997 HCM*)

Level of service	Space (m^2/ped)
A	≥12.08
B	≥ 3.72
C	≥ 2.23
D	≥ 1.39
E	≥ 0.56
F	< 0.56

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In pedestrian crosswalks, the desirable level of service corresponds to LOS B or higher (McShane et al., 1998). LOS F is the worst scenario that can be observed in pedestrian facilities. In the following sections, methodologies for estimating the required pedestrian crossing time are reviewed.

2.2.2.1.2. Qualitative LOS of Pedestrian Facilities

Sarkar (1993) presented a qualitative evaluation of pedestrian facilities based on observations of pedestrians in Rome and Munich. A pedestrian mall, several walkways, a bus stop, and intersection crosswalks were evaluated using qualitative criteria of safety, security, comfort and convenience, system coherence and attractiveness. Pedestrian environments were classified into six service levels. The author described a realistic and a desired level of service in a pedestrian area where the right of way is shared by different modes through horizontal and vertical grade separation. Attention was given into making the environment pedestrian-friendly, especially for captive pedestrians. It was also pointed out that traffic planners and designers have ignored the importance of intermodal connectivity and facilities that enhance such transfers in pedestrian environments.

Khisty (1993) described a practical method of assessing pedestrian facilities using environmental factors. Assessment of environmental factors was accomplished through appropriate performance measures, including attractiveness, comfort, convenience, safety, security, system coherence, and system continuity. Qualitative level of service was used to supplement the quantitative level of se

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quantitative level of service of the facility on the basis of flow, speed, and density units as described in Chapter 13 of the 1997 *Highway Capacity Manual*.

2.2.2.2. Pedestrian Crossing Times at Signalized Crosswalks

Several methodologies are available to estimate pedestrian crossing times at signalized crosswalks. Some of them are applicable to low volume conditions and do not consider platoon movements, while others consider only one-way platoons. In the following sections, existing methodologies to calculate pedestrian crossing times at signalized crosswalks are summarized.

2.2.2.2.1. 1997 Highway Capacity Manual (HCM) Models

The 1997 U.S. *Highway Capacity Manual (HCM)* utilizes two formulae to calculate pedestrian crossing times. Chapter 13 of the 1997 HCM is devoted to pedestrian issues and proposes Equation 2.3 for calculating pedestrian crossing time, *T*, at signalized crosswalks:

$$T = L / u \quad \text{Eq.2.3}$$

where

T = pedestrian crossing time (sec),

L = pedestrian crossing distance (m), and

u = pedestrian crossing speed (proposed default value =1.37 m/sec or 4.5 ft/sec).

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On the other hand, Chapter 9 of the 1997 HCM (which focuses on signalized intersections) defines the minimum crossing time for meeting pedestrian requirements, *T*, as:

$$T = D + (L/u) \qquad \text{Eq.2.4}$$

where

T = pedestrian crossing time (sec),

D = pedestrian initial start-up delay (sec),

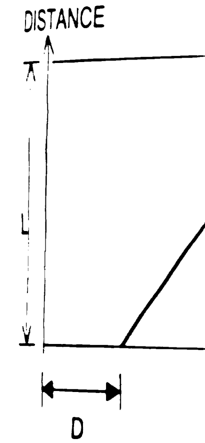
L = pedestrian crossing distance (m), and

u = pedestrian crossing speed (proposed default value=1.22 m/sec or 4.0 ft/sec).

Figure 2.2 shows a time-space diagram for a single pedestrian crossing movement based on the formulation presented in Equation 2.4.

There are two differences between the two formulations proposed in the 1997 HCM for crossing time estimation. First, pedestrian initial start-up delay is ignored in the formula in Chapter 13 but accounted for in the formula in Chapter 9. Second, the definition of pedestrian crossing speed used differs from one methodology to the other.

The pedestrian initial start-up delay, *D*, refers to the time it takes the pedestrian to step off the curb and enter crosswalk after a pedestrian signal indication becomes green. The proposed default value in Chapter 9 of the 1997 HCM is 7 sec (*D*=0 in Chapter 13).



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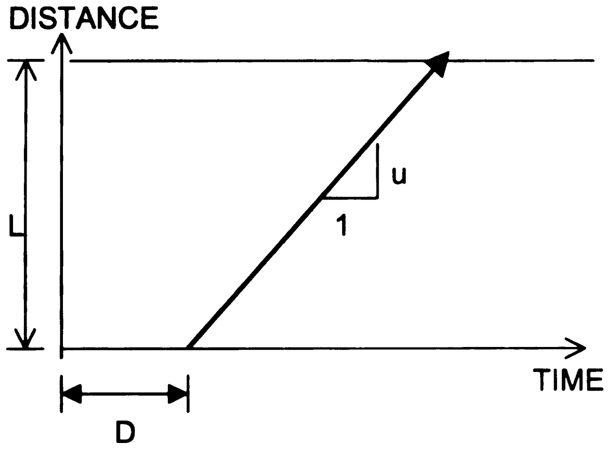

Figure 2.2. Time-space diagram for a single pedestrian (Virkler, 1995)

Moreover, Chapter 13 uses the average pedestrian walking speed as the recommended pedestrian crossing speed, *u*, with a default value of 1.37 m/sec (4.5 fps). Chapter 9, on the other hand, assumes as pedestrian crossing speed, *u*, the 15^{th}-percentile walking speed of pedestrians with a recommended default value of 1.22 m/sec (4.0 ft/sec). This modification is intended to accommodate crossing pedestrians who walk at speeds lower than the average.

Overall, the formulation offered in Chapter 9 (Equation 2.4) is more conservative than the one provided in Chapter 13 (Equation 2.3), while the formula in Chapter 9 appears to address pedestrian crossing needs in a more realistic manner.

2.2.2.2.2. MUTCD Model

The Manual on Uniform Traffic Control Devices (MUTCD) proposes an equation in a format identical to Equation 2.4, with the exception that the start-up delay, *D*, varies from 4 to 7 sec (MUTCD, 1988).

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$$T = D + L / u + 2(\ldots$$

2.2.2.2.3. Pignataro Model

Pignataro (1973) proposed a model identical to Equation 2.4, and recommended modifications to the range of values of the pedestrian initial start-up delay, *D*, and the pedestrian crossing speed, *u*. He proposed a *D* value equal to or greater than 5 sec, and *u* values in the range of 1.07 to 1.22 m/sec. The proposed crossing speeds in the Pignataro's approach consider crossing needs of users with restricted crossing abilities such as children and the elderly.

2.2.2.2.4. Discussion

All three methodologies presented above (in Equations 2.3 and 2.4) model pedestrian crossing time for individual pedestrians without any consideration for pedestrian platoons. As Virkler et al. (1984 and 1995) indicate, the crossing time, *T*, in the above models shall be sufficient if only a small number of pedestrians use the crosswalk during a given phase. However, in the presence of pedestrian platoons, time *D* may not be sufficient for everyone to leave the curb, and the crosswalk may not be cleared of pedestrians in time *T*.

2.2.2.2.5. ITE Model

The Institute of Traffic Engineers (ITE) School Crossing Guideline (ITE, 1962) describes a methodology for pedestrian crossing time calculation that considers platoon presence in one direction. Pedestrian crossing time, *T*, is described as follows:

$$T = D + L/u + 2[(N/5) - 1] \qquad Eq.2.5$$

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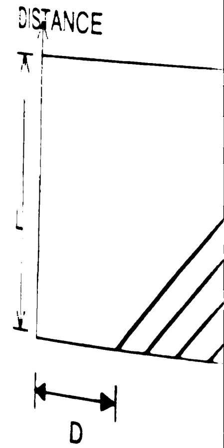

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formulated as follows:

$$T = D + L / u + x($$

where

where

N = number of pedestrians in a platoon of pedestrians crossing during an interval,

and all other variables as defined above. It is assumed that pedestrians walk in rows, five abreast, with a 2-sec headway between rows. Recommended D and u values in the ITE model are 5 sec and 1.22 m/sec respectively. Figure 2.3 shows the time-space diagram for this model.

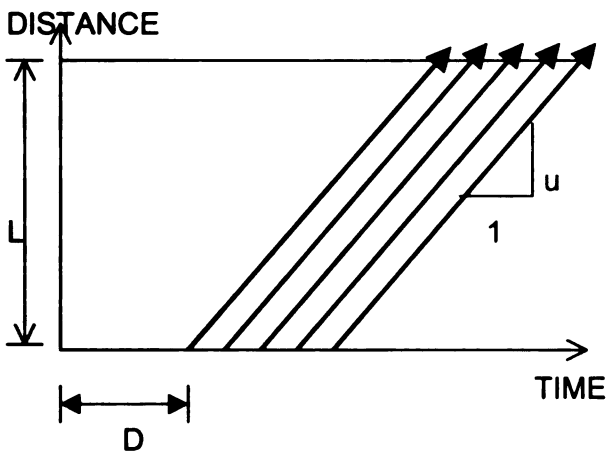

Figure 2.3. Time-space diagram for a one-way platoon (Virkler, 1995)

2.2.2.2.6. Virkler and Guell Model

Virkler and Guell (1984) generalized the concept proposed in the ITE model. Their model considered also the presence of a one-way platoon and is formulated as follows:

$$T = D + L/u + x(N/W) \quad \text{...Eq.2.6}$$

where

x = average p

W = crosswalk

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x = average pedestrian headway (sec/ped/m of crosswalk width), and

W = crosswalk width (m), and all other variables as defined earlier.

Figure 2.3 also applies to this equation. The first term of Equation 2.6 refers to perception-reaction time required by pedestrians to start crossing. The second term represents the time needed by a single pedestrian to cross when moving with speed equal to u and the third term is an adjustment to account for platoon presence. A start-up delay of 3 sec with u=1.27 m/sec, and x=2.61 sec/pedestrian/m can be used as default values.

2.2.2.2.7. Discussion

Although Equations 2.5 and 2.6 recognize pedestrian platoon existence and consider platoon size, they both assume that platoons are formed at one crossing direction only. In reality, it is quite common that two opposite-direction platoons are formed which meet in the crosswalk during time T. If platoon sizes are relatively large, and/or the crosswalk width (W) is small then conflicts between the two platoons are expected which will result in an increase of pedestrian crossing time, T.

Last, but not least, none of the methodologies currently in existence accounts for the effects of turning vehicles (interaction between turning vehicles and pedestrians sharing the same green interval) during the pedestrian crossing phase. Improved methodologies need to be developed to address such issues in the future. However, in this study the issue of developing new methodologies to estimate pedestrian crossing time at signalized crosswalks is out of the scope. It is understood that the

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is understood that the selection of pedestrian walking speed and start-up time in estimating pedestrian crossing time plays an important role, and design values of these variables (speed and start-up time) may affect the proper setting of pedestrian signal timing. Literature review on pedestrian walking speed and start-up delay is given in the following section. In this study, the existing methodologies to estimate pedestrian crossing time are validated using data collected from the study site and some recommendations are made towards the improvement of the existing formulae. The literature review of the interaction between turning vehicles and pedestrians is summarized in the section 2.2.4.

2.2.3. Pedestrian Walking/Crossing Speed and Start-up Time

The characteristics and behavior of pedestrians have not been as thoroughly researched and documented as those of motorists. Literature review shows that there is a considerable variation in the walking/crossing speed of pedestrians depending upon age, trip purpose and environment. In a study on walking speeds, 967 persons were observed in two transportation terminals in New York City. Free-flow walking speeds with an average of 1.4 m/sec (4.6 ft/sec) were observed. 78 percent of the walkers normally walked more slowly. The median speed, which is considered to be more representative than the average speed due to high variance, was 1.2 m/sec (4 ft/sec) (Fruin, 1971). It should be noted that street crossing speeds are expected to be different from walking speeds in terminals/ malls because in street environments through and/or turning vehicles and impending signal change prompt pedestrians to move faster. However, a time-lapse photography study of pedestrians crossing in

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New York City streets showed a lower average crosswalk walking speed of 1.0 m/sec (3.3 ft/sec) (Fruin and Benz, 1984). In order to validate that walking speeds in terminals/malls are lower than those in streets, there is a need for more studies in which walking/crossing speed data are collected at various walking/crossing environments and analyzed further.

The *Manual on Uniform Traffic Control Devices* (MUTCD) recommends normal walking speed to be assumed as 1.2 m/sec (4 ft/sec). However, the New York study indicates that if a walking speed of 1.2 m/sec (4 ft/sec) is used to determine the pedestrian clearance interval, 50 percent of pedestrians have to walk faster than their normal walking speed to cross safely within the allocated time. The *Institute of Transportation Engineers (ITE) Handbook* suggests that a normal walking speed of 1.2 m/sec is acceptable but speeds of 0.9 to 1.0 m/sec (3.0 to 3.3 ft/sec) may be appropriate for slow walkers (Homburger et al., 1982). The 1965 edition of the ITE handbook estimated 35 percent of the pedestrians did not attain the 1.2 m/sec rate (Baerwald, 1965). A study of walking speed conducted in Florida at a location with a large number of elderly pedestrians determined that a walking speed of 0.8 m/sec (2.5 ft/sec) was appropriate for 87 percent of those pedestrians (ITE Committee 4A-6, 1992). A Swedish research team studied pedestrians aged 70 years or older who were instructed to cross an intersection at fast, very fast, and normal speed. The results indicated that 60 percent of the pedestrians considered a speed lower than 1.2 m/sec as fast. Approximately 90 percent crossed at a speed lower than 1.2 m/sec, with 15 percent walking at a speed less than 0.7 m/sec (2.3 ft/sec) (Dahlstedt, undated).

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Knoblauch et al. (1996) conducted a series of studies to quantify walking speed and start-up time of pedestrians of various ages under different conditions. The results of the study are summarized in Table 2.2. Comparing the start-up

Table 2.2. Pedestrian walking speed (mean) and start-up time (85th percentile)

Pedestrians by age	Walking speed, m/sec (ft/sec)				Start-up time, sec			
	Min	Max	Avg	Design value	Min	Max	Avg	Design value
Older (≥65 yrs)	1.14 (3.73)	1.29 (4.24)	1.21 (3.98)	0.91 (3.00)	3.66	3.95	3.76	3.75
Younger (<65 yrs)	1.38 (4.51)	1.56 (5.12)	1.46 (4.79)	1.22 (4.00)	2.76	3.31	3.06	3.0

times suggested in Table 2.2 and the ones used in the formulae presented in section 2.2.2.2, one can suspect that the formulae might overpredict pedestrian crossing time due to high *D* values utilized. On the other hand, at locations where elderly constitute a large portion in the pedestrian volume, the formulae might underpredict the crossing time due to the use of walking speeds higher than actual. In addition, pedestrian subjects in Table 2.2 were divided into two very broad categories. It is expected that the average design speed for youngsters (e.g., between 18 and 25 years old) might be higher than the speed suggested for the younger pedestrians (<65 years old) in Table 2.2. In that case, again, for design purposes a walking speed higher than 1.22 m/sec should be selected.

Bowman and Vecellio (1994) performed a study of pedestrian walking speeds and conflicts. The study sites were urban and suburban medians located

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on unlimited-access arterials. Pedestrian walking times were measured on three types of cross sections: raised median, two-way left-turn (TWLT), and undivided arterial streets. Pedestrian speeds were computed for three-age categories: <18 years old, between 18 and 60 years old, and >60 years old. Statistical tests were used to determine the effect of median type, crossing location (midblock vs. signalized intersection), and pedestrian age on walking speeds. The results indicated that pedestrian walking speeds were a function of age and crossing location. The following conclusions on pedestrian walking speeds were made for raised, TWLT, and undivided median streets in CBD and suburban environments:

- Pedestrians aged 18 to 60 years performed a significantly higher speed at TWLT medians for both signalized intersections and midblock locations than they did at undivided median arterials. They crossed with the speed of 1.47 m/sec (4.81 ft/sec) and 1.46 (4.79 ft/sec) at TWTL medians at signalized intersections and midblock locations, respectively. However, they achieved the speed of 1.17 m/sec (3.84 ft/sec) and 1.19 m/sec (3.90 ft/sec) at signalized intersections and midblock locations, respectively, at undivided median arterials. The increased walking speed at locations with TWLT lane may be due to the increased pedestrian perception for longer walking distance resulting from the presence of the TWLT lane.
- The walking speed for the 18 to 60 year old age group was significantly higher than that for the over 60 year old age group at both signalized

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intersections and midblock locations. Both age groups had significantly higher walking speeds at midblock locations than at signalized intersections, probably because pedestrians felt protected at signalized intersections and did not feel the same urgency to cross as they felt at midblock ones.

The diversity of walking speeds presented by different studies and researchers present a problem in selecting proper walking speed for design purposes to determine minimum green time and clearance interval at signalized intersection crosswalks. The Traffic Control Devices handbook states that "Those having slower walking speeds have the moral and legal right to complete their crossing once they have lawfully entered the crossing" (*Traffic Control Devices Handbook*, 1983). Thus, traffic engineers have to select the appropriate walking/crossing speed to determine the minimum green and the appropriate clearance interval according to the characteristics of pedestrians who are expected to cross the street. Vehicular traffic should also receive a fair treatment by allocating an appropriate green time, and the number of phases and phasing schemes (Bowman and Vecellio, 1994). Pedestrian and vehicular needs, however, usually conflict in selecting optimal signal timing and phasing plans. Then, the optimal solution is to be found by balancing the needs of both types of users (vehicles and pedestrians) and minimizing delay to both.

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2.2.4. Turning Vehicle Pedestrian-Conflicts and Crashes

Conflicts between pedestrians and motor vehicles may create situations for potential crash occurrence. In many signalized intersections, pedestrians and turning-vehicles share the right-of-way (same green time) and compete for traffic priority at signalized intersections.

2.2.4.1. Turning Vehicle-Pedestrian Conflicts

A traffic conflict occurs when the paths of two movements that are competing for the same space (at the same time) cross each other. Traffic conflict areas have an increased potential for collisions. Two types of traffic conflicts are defined by Perkins and Harris (1968):

a. evasive actions of road users, and
b. traffic violations.

The first type refers to a situation where one or both parties take an evasive action to avoid a collision that is imminent. Evasive actions of motorists or bicyclists are evidenced by braking and/or weaving. Evasive actions of pedestrians are evidenced by significant increase of walking speed, running, or waiting for vehicles/bicyclists to clear prior to crossing a roadway. On the other hand, traffic violations are defined as violations of the pedestrian right-of-way by vehicles, when the right-of-way of pedestrians over vehicles is clearly indicated by posted signs.

Actual pedestrian-vehicle conflicts are defined by Davis et al. (1989) as situations where the projected path of a turning vehicle and a pedestrian cross and either the pedestrian or the vehicle, or both, must change direction and/or speed to avoid a co

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speed to avoid a collision. This definition is appropriate to use when examining the relationship between conflicts and crashes, because actual conflicts between vehicles and pedestrians create a potential for vehicle-pedestrian crashes. In order to analyze the impact of pedestrian-vehicle interactions on operations of crosswalks, the consideration of potential (not actual) pedestrian-vehicle conflicts appears more appropriate.

Fruin (1973) studied pedestrian crashes on one-way street networks and explored the relationship between pedestrian crashes and turning-vehicle pedestrian conflicts. He reported that 68 percent (172 accidents out of 253) of accidents occurred on the conflict side, where pedestrians and vehicles compete over the same space at the same time. The results of his study show that pedestrian crosswalks that are independent from turning-vehicle pedestrian conflicts show a lower pedestrian accident experience. If a signalized intersection has a significant number of turning-vehicle pedestrian crashes (e.g., ≥ 20-25 accidents/year), turning restrictions have to be applied despite the potential increase of total delay for vehicle traffic. Turning restrictions do not have to be implemented all day long. They can be applied only during pedestrian-peak hours. Fruin also quotes that pedestrian accidents with left-turning vehicles were two times higher than pedestrian accidents with right-turning vehicles. When conditions allow, left-turning vehicle-pedestrian conflicts can be reduced by applying early/late release of pedestrians.

Sisiopiku and Akin (1999:2) analyzed pedestrian perceptual and movement data obtained in a small city/college environment and concluded that pedestrian and turn

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pedestrian and turning vehicle conflicts at signalized intersections increase the likelihood that pedestrian users will cross the road improperly (in non-crosswalk locations) to avoid such conflicts. Improper crossing refers to crossing during pedestrian DON'T WALK (red) signal, or at a non-designated crossing location.

2.2.4.2. Turning Vehicle-Pedestrian Crashes

Quaye et al. studied pedestrian crashes with left-turning vehicles at signalized intersections. They concluded that left-turn vehicle-pedestrian crashes at signalized intersections are over-represented and become a very important road safety problem (Quaye et al., 1993). They also developed models predicting expected number of such crashes on the basis of the flow of left-turning vehicles and pedestrians. They examined how two typical signal schemes for accommodating left-turn vehicles influenced the number of left-turn vehicle crashes with pedestrians. The signal schemes studied were semi-protected and permissive schemes. In a semi- protected scheme, left-turning vehicles face no opposing traffic but conflict with pedestrians. In a permissive scheme, left-turning vehicles have to find suitable gaps in the opposing traffic. The results indicated that semi-protected left turns were safer for pedestrians at low left-turning vehicular flows. The opposite is true for high flows of left-turning vehicles.

The literature also reports that left-turn vehicles are approximately four times more dangerous to pedestrians than through movements (Habib, 1980; Fruin, 1973). Abdulsattar et al. reported that left- and right-turn movements at signalized intersections were three to six times more hazardous to pedestrians than through movements, mainly because drivers fail to observe or yield to pedestrians (Abduls

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pedestrians (Abdulsattar et al., 1996). Almuina (1989) examined crashes involving left-turning vehicles and pedestrians at signalized intersections during a three-year period and reported that approximately 32 percent of pedestrian crashes at signalized intersections occurred with left-turning vehicles. These findings should be taken under consideration by traffic engineers that design pedestrian signals and signal phasing plans. The following section summarizes studies about pedestrian signs and signals.

2.2.5. Pedestrian Signs, Signals and Alternative Signal Schemes

Pedestrian signs and signals are of great importance in pedestrian crosswalk operations. Signs and signals should be properly placed and times for increased safety and operational efficiency. Different signal schemes have different impacts on the safety of pedestrians and vehicles. Since pedestrians are much more vulnerable than vehicles, traffic control must be designed with extreme care. Improper and/or confusing messages conveyed to pedestrians by traffic control may result in conflicts between pedestrians and vehicles with serious safety consequences.

2.2.5.1. Pedestrian Signs and Signals

A clear indication of when pedestrians can walk without expectations of conflicts with vehicle traffic is the most useful information for pedestrians (Robertson and Carter, 1984). Pedestrian signals may also help pedestrians in estimating the safe crossing time remaining. A study at signalized intersections where there was no pedestrian signal by Mortimer (1973) showed that pedestrian flow that crossed the

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flow that crossed the street was the highest during the yellow interval. Obviously, crossing the street during yellow signal creates a potentially dangerous situation because the imminent change of the traffic signal to green for vehicular traffic may put pedestrians crossing the road in danger. This study shows a great safety benefit of pedestrian signal indications at signalized intersection crosswalks (Carter, 1984). However, there has been a concern about a particular aspect of pedestrian signals. Sleight (1972) noted that the meaning of pedestrian signals used in practice was not always clear. Usually the solid green indication of "WALK" means that the pedestrian has exclusive right-of-way and no conflict with motorists. However, in the majority of cases, vehicle traffic is permitted to turn onto the crosswalk during the WALK indication. Therefore, a pedestrian may not clearly know which type of control is in effect at a particular intersection. Pedestrians who encounter exclusive crossing phasing have a different set of expectations than those who are required to watch for turning vehicles during the WALK signal indication (Robertson and Carter, 1984).

Some cities such as Washington, D.C. have a different way of using the WALK indication. The green WALK signal flashes at intersections where there are potential conflicts between turning vehicles and crossing pedestrians. However, a similar problem occurs in that the flashing WALK and DONT WALK signal indications convey two completely different messages. The flashing WALK indicates a warning for pedestrians about turning vehicles whereas the flashing DONT WALK indicates the clearance interval; that is, the signal is about to change to the solid DONT WALK indication and pedestrians should not leave the curb and step on th

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curb and step on the crosswalk. Again, pedestrians who have never encountered the flashing WALK indication might not know what to expect from the flashing green WALK signal. However, pedestrians may have a poor understanding of the meaning of flashing and solid green WALK signals if they both are used together in the same vicinity. Another risk is that, if pedestrians do not understand the message given by the signal, they might ignore the signal completely (Robertson and Carter, 1984).

Robertson (1977) reported that out of 400 pedestrians surveyed in two cities, only 2.5 percent understood the intended meanings of flashing and solid WALK. Less than half of the pedestrians in both cities said that they would expect vehicles to be turning onto the crosswalk during the WALK interval. Turning vehicles in both cities constituted one-fourth of the total traffic passing through the intersections and all turns were permitted.

It is believed that standardization of the information provided by signals will increase pedestrian crossing compliance with the signal. When the types of messages given to pedestrians vary from place to place, then pedestrians should be given provisions to identify the differences. Otherwise, pedestrian compliance with signal is expected to be low.

Zeeger et al. (1984) pointed out that one of the major pedestrian safety problems in the US is due to the confusion associated with pedestrian signal indications. Pedestrians usually do not comply with pedestrian signals because of lack of understanding or respect for the signals. The violations of the DONT

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WALK message were found to be higher than 50 percent in many cities (Robertson, 1982).

Zegeer et al. (1984) developed and evaluated innovative pedestrian sign and signal alternatives, including the clearance interval (in place of the flashing DONT WALK message) and pedestrian warnings of possible turning vehicles (instead of the flashing WALK message). Of 41 alternatives developed, the eight most promising ones were evaluated at several sites in five US cities. These include "WALK WITH CARE" sign for pedestrians, "YIELD TO PEDESTRIANS WHEN TURNING" regulatory sign for motorists, "PEDESTRIANS WATCH FOR TURNING VEHICLES" warning sign for pedestrians, and a pedestrian signal explanation sign (word and symbolic). The following conclusions were drawn from the study:

- The results from the evaluation of the pedestrian signal explanation sign were mixed. The sign did not demonstrate any effect on pedestrian compliance at two sites (Saginaw, Michigan), while the sign was effective at two other sites (Washington, DC) in reducing pedestrian violations and turning conflicts. The ineffectiveness of the sign at the two Michigan sites was thought to be related to the existing already-safe base conditions for pedestrians (more than 80 percent pedestrian compliance was observed in the sites before the sign tests were implemented). However, in Washington DC, the study sites showed only 56 percent of compliance in the base period and more improvement compared to base conditions.

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- When compared to the flashing DON'T WALK display, the steady DONT START clearance indication using a three-lens pedestrian signal showed a significant improvement in reducing pedestrian violations and associated clearance related conflicts at three of the four sites.
- The steady DONT WALK signal indication used for the clearance interval showed no improvement over the flashing DONT WALK signal.
- The WALK WITH CARE signal used for the walk interval and aimed at warning pedestrians for the turning vehicles was found to be effective in reducing turning vehicle-pedestrian conflicts as well as pedestrian violations at the four sites.
- The YIELD TO PEDESTRIANS WHEN TURNING sign was found to be effective in reducing pedestrian conflicts with turning vehicles, particularly with right-turning vehicles.
- The PEDESTRIANS WATCH FOR TURNING VEHICLES sign was also found to be effective in reducing pedestrians conflicts with right-turning vehicles. This sign could be used in conjunction with the YIELD TO PEDESTRIANS WHEN TURNING sign.
- The flashing WALK signal did not show any proven benefit over the steady WALK signal in warning pedestrians for turning vehicles that shared the same green with pedestrians. According to the study by Robertson (1982), the difference between the steady and flashing

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Abdulsattar et al. (1996) studied the effect of "TURNING TRAFFIC MUST YIELD TO PEDESTRIANS" sign. This sign aims at reminding turning motorists to yield to pedestrians who share the same signal phase with turning vehicles. Vehicle-pedestrian conflicts were collected at 12 marked crosswalks in two cities before and after the sign was installed. The authors reported that the sign was effective in reducing left- and right- turn conflicts 20 to 65 percent and 15 to 30 percent, respectively. Based on the results of the study, the "TURNING TRAFFIC MUST YIELD TO PEDESTRIANS" sign was recommended for inclusion in the Manual on Uniform Traffic Control Device.

2.2.5.2. Alternative Pedestrian Signal Schemes

Abrams et al. (1977) presented a methodology for selecting alternate phasing plans for pedestrian signals. They compared "combined pedestrian-vehicle interval" (where pedestrians and vehicles compete for priority over the same space and time), "early" and "late release" of pedestrians with respect to vehicles, and "scramble timing." In a phase of scramble timing, vehicles from all approaches are stopped and the exclusive right-of-way is given to pedestrians. Each alternative was weighed in terms of its impact on the safety of the pedestrians and the delay to both pedestrians and vehicles. The results of the study showed that the combined pedestrian-vehicle interval almost minimized overall pedestrian and vehicle delay with the exception of turning-vehicle pedestrian conflicts

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pedestrian conflicts that cause long queues of vehicles in turning lanes. In that case, late or scramble timing is preferable. The total delay is always increased by the application of late release for low vehicle volumes. However, the results for high traffic volumes are mixed. If there is a high demand for right-turning vehicles and high pedestrian crossing volumes, the use of late release significantly reduces vehicle delay. The use of late release increases the capacity of right-turn lane by concentrating pedestrian flow in a short time and allowing pedestrians to cross at the end of the phase. Scramble timing can be beneficial to pedestrian safety by completely separating pedestrian and vehicular traffic; however, this method can not be justified in terms of overall delay if pedestrian compliance is low. Finally, the early release of pedestrians does not appear to significantly improve pedestrian safety while it increases total delay at the intersection. A methodology for selecting the phasing for given pedestrian and turning-vehicle volumes was also presented.

2.3. Pedestrian Perception and Preference Studies

Pedestrian attitudes and preferences are very important criteria for traffic engineers and city planners. Pedestrians are an important group whose perceptions and preferences need to be addressed in designing any facilities used by pedestrians. However, this does not mean that pedestrian facilities are to be installed in locations where they are not recommended by traffic engineering studies because marked crosswalks can also be target locations for pedestrian-vehicle accidents because pedestrians see marked crosswalks as places warranted for them to cross. Marked crosswalks sometimes may give a false sense of secu

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Although considerable research has been undertaken on the general problem of pedestrian safety, limited studies on pedestrians' perceptions and preferences are reported in the literature. Among them, the research of Tanaboriboon and Jing (1994) studied preferences of pedestrians in China toward sufficiency of crossing facilities and willingness to use the facilities. The study compared signalized intersection pedestrian crossings with overpass and underpass crossings and concluded that users prefer signalized crossings to overpass or underpass crossings.

Rouphail (1984) performed a user compliance and preference study on marked midblock crosswalks in downtown Columbus. The preference study indicated that users perceived the unsignalized marked midblock crosswalk to be unsafe. However, the same crosswalks are rated highest in crossing convenience. The survey also indicated that neither motorists nor pedestrians seemed to favor the signalized marked midblock crosswalks, most likely because of increased dela

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After reviewing design-related researches and pedestrian perception/preference studies, pedestrian safety studies also need to be reviewed. The following section reports the issues of pedestrian safety in general and pedestrian safety in crosswalks in particular.

2.4. Pedestrian Safety Studies

Pedestrians constitute the second most vulnerable category in motor vehicle crash deaths after occupants. Pedestrian deaths account for approximately 13 to 17 percent of motor vehicle deaths. The share of elderly population in those deaths is major (*Pedestrian Accident Statistics, online*, 1999). Although pedestrian safety has improved in the recent years, it remains an issue of concern as pedestrian related crashes result in a high number of fatalities and injuries. In 1998 and 1988, 3700 and 4355 pedestrian related accidents occurred in Michigan, respectively, which resulted in 173 fatalities and 3208 injuries, and 245 fatalities and 4228 injuries, respectively (*Michigan Crash Reports*, 1988-98).

The following facts are based on the analysis of data from the US Department of Transportation's Fatal Accident Reporting System (FARS) (*Pedestrian Accident Statistics, online*, 1999):

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- 5,412 pedestrians died in 1996, slightly lower than in 1995 (5,585). Since 1975, 13 to 17 percent of motor vehicle crash deaths involved pedestrians.
- Pedestrian deaths per 100,000 people decreased 39 percent between 1975 and 1996 (from 3.5 to 2.1 deaths per 100,000).
- Pedestrian deaths per 100,000 people zero to nine years old decreased by 70 percent between 1975 and 1996.
- 58 percent of pedestrians age sixteen and older, who were killed in nighttime motor vehicle crashes in 1996, had blood alcohol concentrations at or above 0.10 percent.
- Seventeen percent of pedestrian deaths occur in hit-and-run crashes.
- Male pedestrians account for 2 out of every 3 pedestrians deaths.
- People age 65 and older have more than twice as many pedestrian deaths per 100,000 people compared to younger groups, even though the rate of pedestrian fatalities among the elderly has been declining since the 1950s.
- At age 80 and older, the 1996 pedestrian death rate among men was more than three times as high as at age 74 and younger.
- Fatal pedestrian-motor vehicle collisions occur most often between 6 and 9 P.M.
- Pedestrian deaths are more likely to occur on Friday and Saturday than other days.

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After providing these facts about the pedestrian safety in general, in the following paragraphs, statistics and research findings related to the issue of pedestrian safety in crosswalks are presented next.

2.4.1. Pedestrian Safety in Crosswalks

Pedestrian deaths are mainly a problem in urban settings. Many pedestrians are killed in crosswalks, sidewalks, median strips, and traffic islands. The following statistics are based on data from FARS (*Pedestrian Accident Statistics, online*, 1999):

- 69 percent of pedestrian deaths in 1996 occurred in urban areas. However, the ratio of deaths to injuries is higher in rural areas because of higher impact speeds on rural roads.
- 33 percent of pedestrian deaths among people age 65 and older in 1996 occurred at intersections. Moreover, 12 percent of pedestrian deaths occurred among children age 4 and younger.

A majority of the pedestrian-vehicle accidents in 1996 (82%) occurred in urban areas. Approximately 25 percent of pedestrians were killed or injured while crossing or entering intersections (*Pedestrian Accidents Statistics, online*, 1999). It should be noted that the vast majority of pedestrian crashes were caused by pedestrian violations of right-of-way (e.g., crossing during DONT WALK signal, crossing at a non-designated crossing area, crossing without observing the right-of-way, and so on).

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A study in the late fifties reported some interesting findings about pedestrian violations at signalized intersections (Orne, 1959). In this study, pedestrian violations, as well as pedestrian and vehicle volume data were collected at signalized intersections with and without pedestrian signals in two cities. The analysis results showed that pedestrian violations were positively correlated with both pedestrian and vehicle volumes although pedestrian characteristics were shown to be different in the two cities. The correlation was higher at the intersections where a pedestrian signal was present than at unsignalized ones. It is obvious that pedestrians ignore traffic signals when they think that they can safely cross the street. Long gaps in vehicular traffic stream encourage pedestrians to ignore signals while attempting to cross.

2.5. Summary and Conclusions

Many cities around the country are trying to make urban and downtown areas pedestrian and bicycle friendly environments. City planners and traffic engineers need evidence of what types of designs are appreciated by pedestrians and those attract and safely serve for non-motorized users.

The literature review of the different topics related to the research study showed the importance of determining the effectiveness of various pedestrian crossing options and treatments. However, an evaluation of various different crossing options in a same environment has not been found in the literature. In order to make reasonable comparisons and exclude site specific characteristics from study results, it is imperative to assess pedestrian crossing options under similar conditions in a same environment. For this reason, Grand River Avenue in downtown East

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downtown East Lansing has been identified to assess various pedestrian crossing options and facilities in a same test corridor in order to exclude external factors from study results and make comparisons meaningful with respect to the effectiveness of the crossing locations.

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Chapter 3

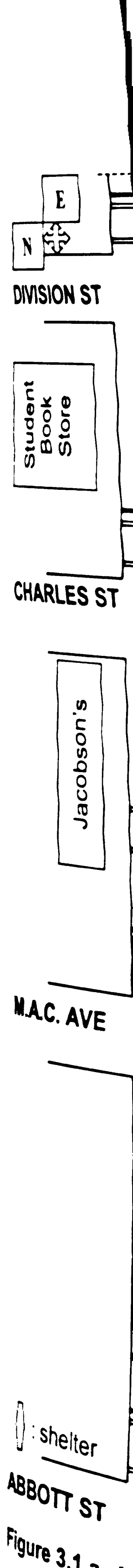
OPERATIONAL ANALYSIS OF PEDESTRIAN CROSSING OPTIONS: STUDY OF PEDESTRIAN CROSSING COMPLIANCE AND BEHAVIOR

3.1. Introduction

In this chapter, the effectiveness of various pedestrian crossing options is studied by determining pedestrian crossing compliance using field data from Grand River Avenue in downtown East Lansing, Michigan. The study site extends from Abbott Street to Bogue Street and is approximately 1 km (0.63 mi) long. Eastbound vehicular traffic is served by two lanes and westbound by three. A local bus service is provided on both directions by the Capital Area Transportation Authority. Pedestrian crosswalk lengths vary from 27.8 to 37.9 m (91.2 to 124.3 ft). To facilitate the data collection, the study site is divided into two sections. Figures 3.1.a and b show the schemes of the study site by section.

The study site offers an appropriate environment for evaluation of various pedestrian crossing treatments. Such treatments include:

1. signalized intersection crosswalks,
2. unsignalized intersection crosswalks,
3. marked midblock crosswalks,
4. non-striped midblock crosswalks, and
5. median shelters at midblock crosswalk locations and physical barriers along the study site.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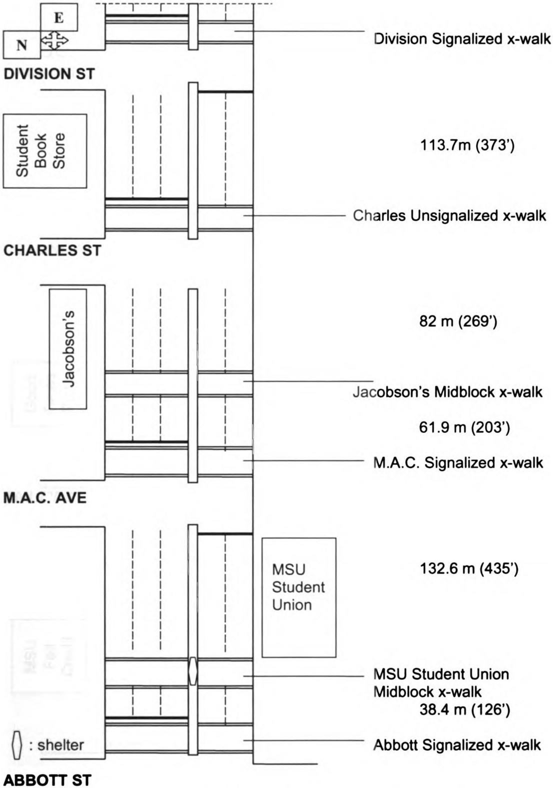

Figure 3.1.a. A scheme of the study site: section 1 (not to scale)

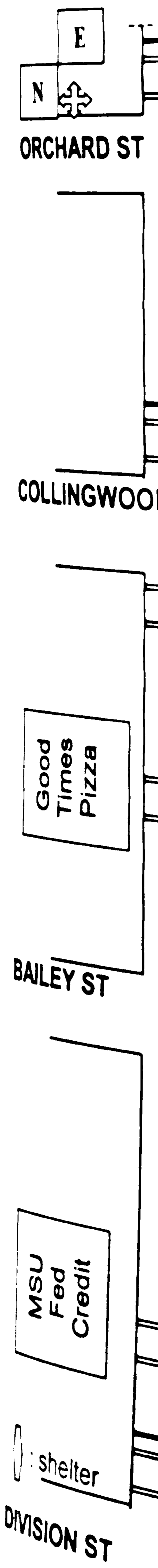

Figure 3.1.b. A s

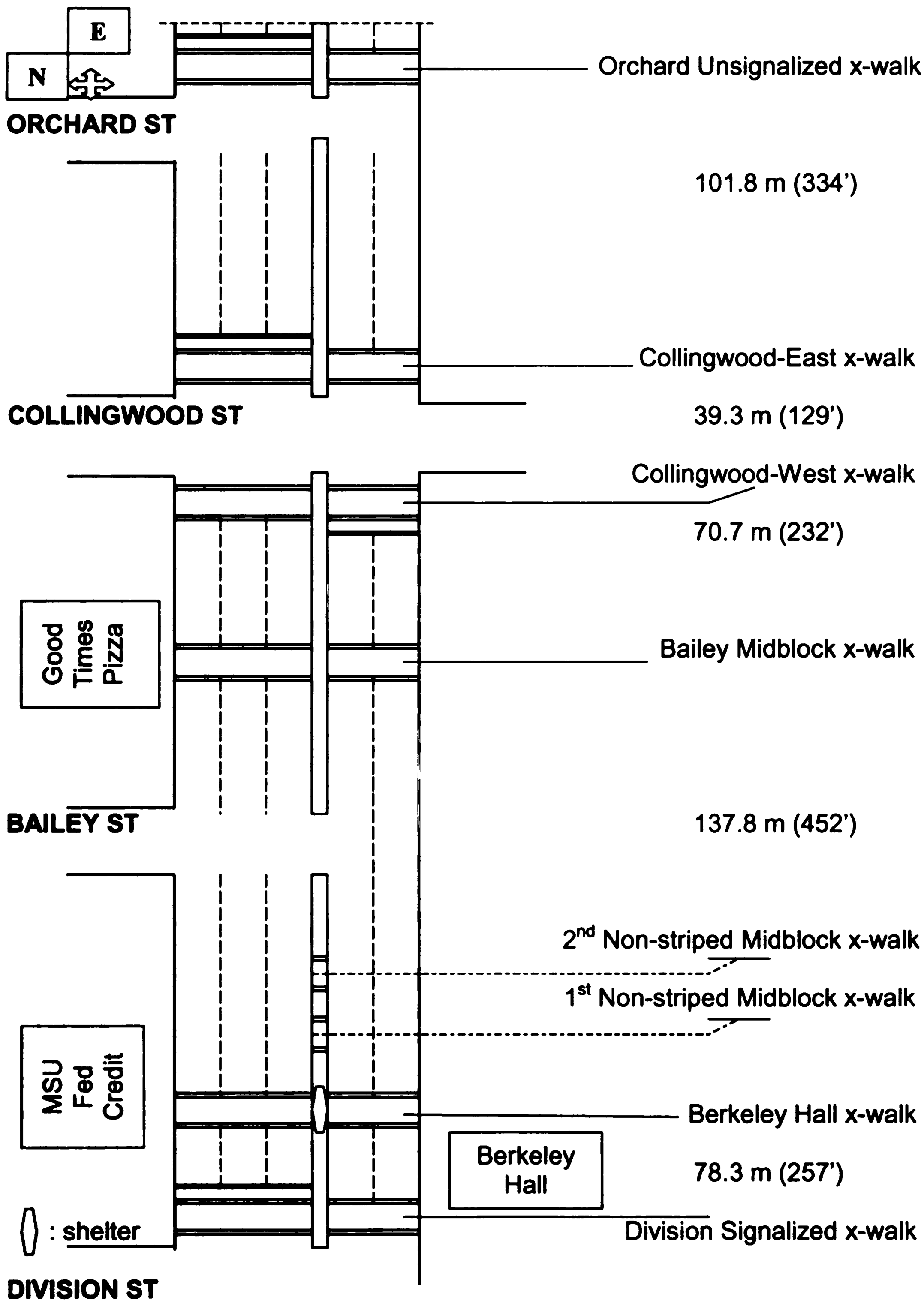

Figure 3.1.b. A scheme of the study site: section 2 (not to scale)

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Four signalized intersections with crosswalks are located within the study site. Three of these intersections (Abbott, MAC and Division) have a crosswalk at one side (east side), and the fourth intersection (Collingwood) has crosswalks at both sides. With respect to signal phasing, the westbound vehicle traffic receives a red indication 5-6 sec earlier than the eastbound at two of the signalized intersections (Abbott and Division). The purpose of this arrangement is to allow the movement of eastbound left-turning vehicles onto cross streets. During the 5-6 sec period in which westbound traffic is stopped and eastbound traffic is moving, the pedestrian signal remains red. However, one should keep in mind that pedestrians traveling southbound can safely cross the westbound portion of the roadway (since westbound traffic is stopped), despite the red indication of the pedestrian signal. Finally, two crosswalks are located at the unsignalized intersections (Charles and Orchard).

Marked midblock crosswalks are located between two consecutive intersections. They are striped, paved with red-colored bricks at the median and curbs, and have warning signs posted. The warning signs display the message "cross only when traffic clears." There are four marked midblock crosswalk locations within the study area, two of which have shelters at the median (MSU Student Union and Berkeley Hall). Non-striped midblock crosswalks, on the other hand, have red-color brick pavement at the median, but they lack stripes and signs. Two non-striped midblock crosswalks exist within the study area. Both are located to the east of Division Street, just east of the Berkeley Hall marked midblock crosswalk.

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In summary, the study crosswalks can be stratified as follows:

1. Signalized intersection crosswalks with one-side pedestrian crossing (Abbott, M.A.C., and Division Streets);
2. Signalized intersection crosswalk with two-side pedestrian crossings (Collingwood Street);
3. Unsignalized intersection crosswalks (Charles and Orchard Streets);
4. Marked midblock crosswalks with the shelter (Student Union and Berkeley Hall);
5. Marked midblock crosswalks without the shelter (Jacobson's and Bailey Street); and
6. Non-striped midblock crosswalks (just east of Berkeley Hall).

3.2. Methodology

The effectiveness of the pedestrian crosswalks is determined based on "pedestrian crossing compliance." The crossing compliance rate (percent) is defined as the number of pedestrians (per hour) who cross at a crosswalk location divided by the number of pedestrians (per hour) in a "crosswalk influence area (CIA)." The definition of the CIA is given next.

3.2.1. Crosswalk Influence Area (CIA)

The analysis was based on the assumption that each crosswalk had an influence area in which it attracted pedestrians crossing the street. In order to determine the crosswalk influence area (CIA) for each study crosswalk, the distance between each pair of consecutive crosswalks was divided into two equal lengths by an in

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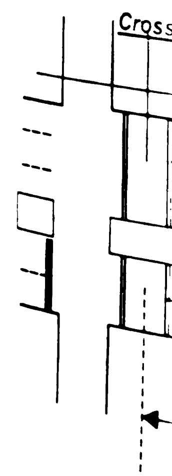

Figure 3.2. Defin

lengths by an imaginary dividing line. As a result, each crosswalk was located between two consecutive dividing lines serving as the boundaries of the crosswalk influence area. The area between the two lines is the so-called crosswalk influence area.

Figure 3.2 demonstrates an example of a crosswalk influence area definition for crosswalk *i*. The distance between crosswalk *i-1* and crosswalk *i* is L_{i-1}. The distance between crosswalk *i* and crosswalk *i+1* is L_{i+1}. Then, the crosswalk influence area (CIA_i) for the crosswalk *i* is the product of the sum of $L_{i-1}/2$ and $L_{i+1}/2$, and the street width from curb to curb. The length of the crosswalk influence area is expressed mathematically by Equation 3.1:

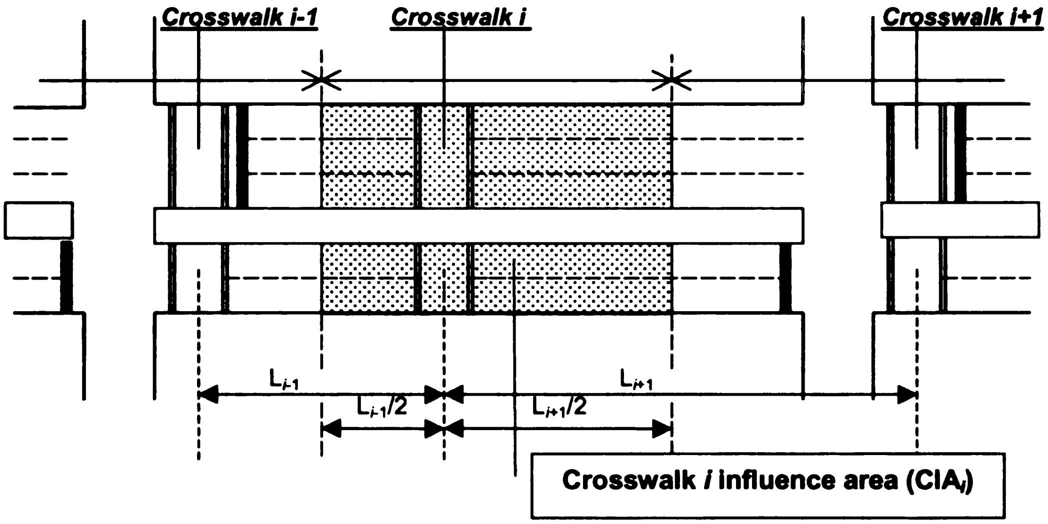

Figure 3.2. Definition of crosswalk influence area

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$$L^{i}_{CIA} = \frac{L_{i-1} + L_{i+1}}{2} \quad \text{......} \quad Eq.3.1$$

where

L^{i}_{CIA} = length of the crosswalk influence area for crosswalk *i* (m),

L_{i-1} = distance between crosswalks *i-1* and *i*,

L_{i+1} = distance between crosswalks *i* and *i+1*, and

crosswalks *i-1*, *i*, and *i+1* are three consecutive crosswalks.

The definition of the crosswalk influence area (CIA) for different types of crosswalks does not differ. The distance between two consecutive crosswalks is simply divided by two in order to calculate the distance of a CIA for any crosswalk.

3.2.2. Pedestrian Crossing Compliance Rates (PCCR)

The measure of "pedestrian crossing compliance rate (PCCR)" was employed in this study to compare various crossing options and assess their effectiveness. This measure is defined as the ratio of the number of pedestrians who comply with the crosswalk location and/or the pedestrian WALK signal over the total number of pedestrians in the crosswalk influence area (CIA). Pedestrians who comply with the crossing location *i* (denoted as P^{i}) are those that cross within approximately 3.0 m (10 ft) from both sides of the crosswalk *i* (see Figure 3.3 for the definition of a crosswalk area).

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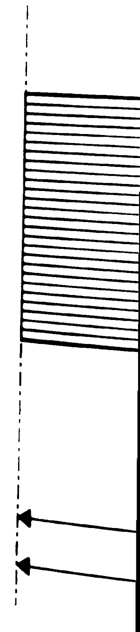

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Regarding the definition of the crosswalk area (CA) for the intersection crosswalks, one might think that the area where pedestrian type 1 or 3 in Figure 3.3 walks is not available at the intersection crosswalks. Therefore, the length of

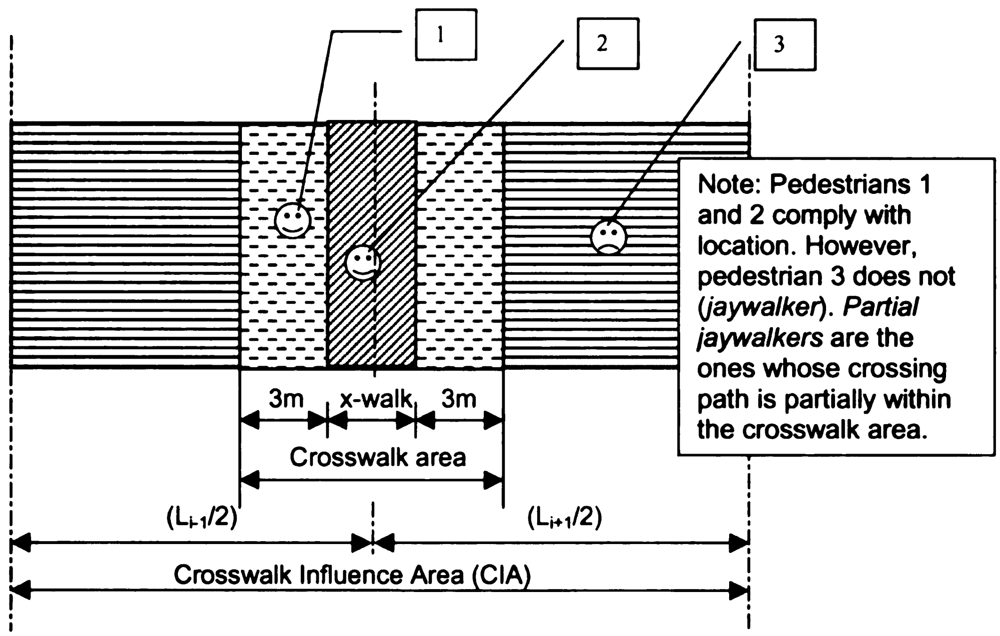

Figure 3.3. Definition of crosswalk area for calculation of PCCR

the crosswalk area for intersection crosswalks might be shorter than that of midblock crosswalks. However, this is not the case in the study area because there is usually a buffer area approximately 2-3 meters wide on the west side of the median of the intersections before the actual crosswalk limits begin.

3.2.2.1. Spatial Crossing Compliance Rate (SCCR)

Crossing compliance rates for unsignalized intersection and midblock crosswalks refer to spatial compliance, i.e., with respect to crossing location.

Equation 3.2 gives the definition of the "spatial" crossing compliance rate for crosswalks without a pedestrian signal:

$$SCCR^i = \frac{P_L^i}{P_{CIA}^i} \quad Eq.3.2$$

where

$SCCR^i$ = spatial crossing compliance rate at crosswalk *i* (percent),

P_L^i = number of pedestrians who cross within the crosswalk area, CA, (ped/hr), and

P^i_{CIA} = total number of pedestrians in the crosswalk influence area (CIA) of crosswalk *i* (ped/hr).

The pedestrian crossing compliance rate given in Equation 3.2 measures the degree of the pedestrian crossing compliance with respect to the crossing location only. Thus, it is also proper to use the equation for signalized (intersection) crosswalks when only spatial compliance is a matter of interest.

3.2.2.2. Temporal Crossing Compliance Rate (TCCR)

At signalized crosswalks, pedestrian crossing compliance shall be linked to two elements:

a. compliance with the crossing location (spatial compliance), and
b. compliance with the pedestrian WALK signal indication (temporal compliance).

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Temporal crossing compliance rate, $TCCR^i$, is defined as the ratio of the number of the pedestrians (per hour) who comply with the pedestrian WALK signal indication, P_T^i, over the total number of the pedestrians within the crosswalk area, P_{CA}^i. Temporal crossing compliance rate is shown in Equation 3.3.

$$TCCR^i = \frac{P_T^i}{P_{CA}^i} \quad \ldots\ldots\ldots\ldots \quad Eq.3.3$$

where

$TCCR^i$ = temporal signal crossing compliance rate in signalized crosswalk i (percent),

P_T^i = number of pedestrians who comply with the WALK signal indication (ped/hr), and

P^i_{CA}= total number of pedestrians (per hour) in the crosswalk area (CA) of crosswalk i.

The reason that the denominator in Equation 3.3 is different from the one in Equation 3.2 because it not very meaningful to mention temporal crossing compliance when pedestrians do not comply with the crossing location. Therefore, in determining the temporal crossing compliance, pedestrians only in the crosswalk area (CA) are considered.

3.2.2.3. Overall Crossing Compliance Rate (OCCR)

To combine the spatial and temporal crossing compliances for signalized crosswalks, the concept of overall crossing compliance rate is introduced. Overall crossing comp

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crossing compliance rate, $OCCR^i$, is defined as the ratio of the number of pedestrians (per hour) who comply with both the crossing location and the pedestrian WALK signal indication, P_{LT}^i, over the total number of the pedestrians (per hour) within the crosswalk influence area, P_{CIA}^i. Equation 3.4 gives the definition of OCCR for signalized crosswalks:

$$OCCR^i = \frac{P^i_{LT}}{P^i_{CIA}} \qquad Eq.3.4$$

where

$OCCR^i$ = overall crossing compliance rate in signalized crosswalk i (percent),

P_{LT}^i = number of pedestrians who comply with both crossing location and pedestrian WALK signal indication (ped/hr), and

P^i_{CIA} = total number of pedestrians in the crosswalk influence area (CIA) of crosswalk i (ped/hr).

To compare the effectiveness of crossing options, pedestrian crossing compliance rates were calculated and compared for all the crosswalks in the study area. In addition, volumes on pedestrian paths leading to the crosswalks on Grand River Avenue were investigated in order to have more information about pedestrian flows in the study section.

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3.3. Data Collection

Pedestrian crossing activities were studied through the analysis of field data collected by direct observation using video cameras set up at locations on the sidewalks along the study site. In order to avoid very low pedestrian demand times, data collection sessions were conducted when a reasonable pedestrian volume (about 40-50 ped/hr) was expected to be present at the major intersection crosswalks since the data collection was fairly expensive.

Pedestrian movements were observed and recorded during an off-peak (10:30-1:00 pm) and the PM peak periods (2:30-6:00 pm). Pedestrian movement data were collected mostly during weekdays. Weekend data collection was limited to Saturdays since some shops/stores in downtown East Lansing are not open on Sundays. Data collection was performed during the months that the Michigan State University was in session (Spring and Fall, 1998). Only two data collection sessions fell in late May in order to recover bad video images belonging to previous data collections. Moreover, football home-game weekends and major holidays were excluded. Data collection was performed under various weather conditions (sunny, cloudy, snow sprinklers, cold, warm, and hot). No data were collected under rainy conditions in order to protect the video recording equipment from electrical damages that might occur due to rain.

Eight video cameras were simultaneously used to record pedestrian movements. Video cameras were consecutively located on both sides of Grand River Avenue on the sidewalks along the study section in order to cover all possible ped

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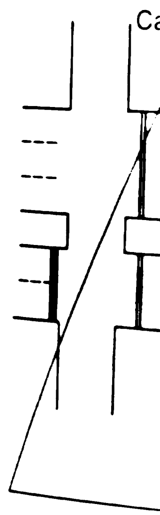

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possible pedestrian movements within the entire study area. An example illustrating typical camera positions is shown in Figure 3.4.

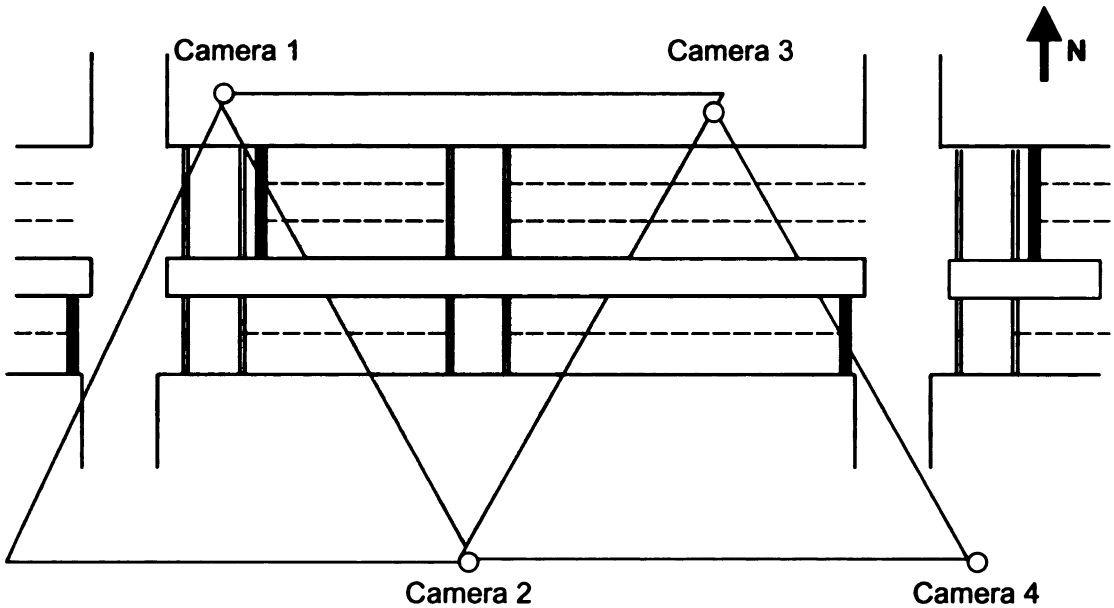

Figure 3.4. Positions of cameras located on the sidewalks along the Grand River Avenue

The recording areas of consecutive cameras were overlapped a little bit to ensure that all pedestrians in the study section were captured. Pedestrian movements were recorded during 30-min sessions at each camera location. Then, cameras were moved to another location. In order to collect a 30-min pedestrian crossing activity data along the entire study site, the cameras were repositioned at least four times. This required a minimum of two hours of work in the field for filming alone, without considering the time involving to start-up and to move the equipment from place to place, and to set it up properly. As a result of this process,

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this process, for each data collection session 16 to 18 hours of video images of the pedestrian crossing activity were recorded.

Though this type of data collection process was a tedious and labor-intensive task, it was very beneficial as it allowed for the detection of every pedestrian movement that occurred in the entire study site during the data collection sessions. Not only the information on pedestrian volume and crossing locations became available but also additional information about conditions during crossing (such as pedestrian signal indication, the presence of other pedestrians and motor vehicles, etc) were obtained through a careful processing of the video tapes in the office.

3.3.1. Study Sections

To facilitate the data collection, the study site was divided into two sections. Section 1 extended from Abbott Street to Division Street, while section 2 covered the distance between Division and Bogue Streets. Section 1 included the following crosswalks:

1. Abbott St four-way intersection signalized crosswalk (located at the east side of the intersection);
2. MSU Student Union marked midblock crosswalk (with a shelter on the median);
3. M.A.C. Ave T-intersection (without a south leg) signalized crosswalk (at the east side of the intersection);
4. Marked midblock crosswalk (without a shelter) in front of Jacobson's, and

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5. Charles St T-intersection (without a south leg) unsignalized crosswalk (at the east side of the intersection).

Section 2 included the following crosswalks:

1. Division St T-intersection (without a south leg) signalized crosswalk (at east side of the intersection),
2. Marked midblock crosswalk (with a shelter) in front of MSU Federal Credit Union (FCU) and Berkeley Hall,
3. Two non-striped midblock crosswalks east of Berkeley Hall,
4. Marked midblock crosswalk (without a shelter) east of Bailey St,
5. Collingwood four-way intersection signalized crosswalks (at both sides of the intersection), and
6. Orchard St T-intersection (without a south leg) unsignalized crosswalk.

There was no crosswalk at Bogue Street intersection during the data collection period. A pedestrian activated signalized crosswalk was installed in December 1998.

Data collection crew videotaped one section at a time recording pedestrian activities for a 30-min session, as described above. Several visits were performed to each section during weekdays and some Saturdays.

3.3.2. Data Collection Dates and Times

Pedestrian movement data were collected from February through June 1998, and in September 1998. Tables 3.1 and 3.2 summarize the dates of the dat

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data collection sessions for sections 1 and 2, respectively, as well as the time and weather conditions during the data collection.

Table 3.1. Data collection sessions at section 1 (Abbott to Division Streets)

Session No	Date	Day	Starting time	Weather	Temperature
1	2/10/98	Tue	10:43 am	Warm	Low 40s
2	2/14/98	Sat	12:44 pm	Cold, partly cloudy	High 30s
3	2/19/98	Thu	2:33 pm	Cold, cloudy	Mid 30s
4	2/23/98	Mon	2:46 pm	Cold, partly sunny	Mid 30s
5	2/25/98	Wed	2:36 pm	Warm, sunny	High 40s
6	2/26/98	Thu	10:35 am	Warm, sunny	High 40s
7	5/27/98	Wed	10:36 am	Sunny	Mid 80s
8	5/28/98	Thu	3:15 pm	Sunny	Mid 70s

Table 3.2. Data collection sessions at section 2 (Division to Bogue Streets)

Session No	Date	Day	Starting time	Weather	Temperature
1	4/17/98	Fri	3:29 pm	Partly cloudy	High 50s
2	4/20/98	Mon	3:26 pm	Partly cloudy	Low 60s
3	4/23/98	Thu	11:02 am	Sunny	Low 70s
4	4/24/98	Fri	3:26 pm	Sunny	High 60s
5	4/28/98	Tue	10:58 am	Sunny	Low 60s
6	4/30/98	Thu	10:59 am	Cloudy	High 60s
7	9/19/98	Sat	1:00 pm	Sunny	Low 80s

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The following data were recorded for pedestrian movement analyses. Number of pedestrians who:

- start crossing the street during pedestrian WALK signal, if applicable, (regular users),
- partially cross within the crosswalk area (partial jaywalkers),
- do not cross within the crosswalk area (jaywalkers) (see Figure 3.3),
- cross in a signalized crosswalk area during pedestrian DON'T WALK signal (sneakers),
- cross a first portion of a signalized crosswalk during DON'T WALK signal, and then continue crossing during the WALK signal (partial sneakers),
- cross from a curb to the median of a signalized crosswalk during the flashing DON'T WALK signal (late starters), and
- total number of pedestrians within the crosswalk influence area (CIA).

Special efforts were made to avoid double counting of pedestrians that started to cross within the field of view of one camera and completed the crossing within the field of the following camera(s). In some cases, two VCR/TV sets were used to resolve double counting. While watching each tape separately, a record of the time when each and every pedestrian appeared on the screen and significant characteristics of him/her (e.g., wearing red T-shirt or blue jacket, etc.) were recorded. Using such information, pedestrians that appeared in more than one tape in the crosswalk influence area were not counted more than once. Data summary forms were developed to report summary data and calculate the pe

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pedestrian crossing compliance rates. Examples of such forms are given in Figures 3.5 and 6, while the complete set of the forms is provided in Appendix A.

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/23/98, Monday, 35 F, cold, partly sunny **Time:** 2:46p
1- Marked Midblock Crosswalk with shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	45	5	4	54

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the Crosswalk Area = 45 + 5 = 50 peds in 30 min
Total pedestrians in the Crosswalk Influence Area = 54 + 0 + 2 = 56 peds in 30 min
Vehicular Volume (VV) = 2418 veh/hr L_{CIA} = 85.50 m (280.5 ft)

$$\text{Pedestrian Crossing Compliance Rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{45}{56} = 80.4\%$$

Total Pedestrian Volume in the Crosswalk Area = 50 * 2 = 100 peds / hr
Total Pedestrian Volume in the Crosswalk Influence Area = 56 * 2 = 112 peds / hr

2- 1st Non-striped Midblock Crosswalk without shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	42	0	27	69

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the Crosswalk Area = 42 + 0 = 42 peds in 30 min
Total pedestrians in the Crosswalk Influence Area = 69 + 3 + 0 = 72 peds in 30 min
Vehicular Volume (VV) = 1860veh/hr L_{CIA} = 31.70 m (100.0 ft)

$$\text{Pedestrian Crossing Compliance Rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{42}{72} = 58.3\%$$

Total Pedestrian Volume in the Crosswalk Area = 42 * 2 = 84 peds / hr
Total Pedestrian Volume in the Crosswalk Influence Area = 72 * 2 = 144 peds / hr

Figure 3.5. Sample data summary sheet for marked and non-striped midblock crosswalks

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GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)

Date: 2/23/98, Monday, 35 F, cold, partly sunny **Time:** 2:46p

3- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts-30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes in 30 minutes	Total
RU + PS (VS)	47	2	0	11	**49**
PS (VR)	14	1	0	2	**15**
S	32	2	2	3	**36**
LS	9	1	0	1	**10**
Total	**102**	**6**	**2**	**17**	**110**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) LS: Late starters

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 5 peds in 30 min

Jaywalkers from east side of the crosswalk = 3 peds in 30 min

Total pedestrians in the Crosswalk Area = 102 + 6 = 108 peds in 30 min

Total pedestrians in the Crosswalk Influence Area = 110 + 5 + 3=118 peds in 30min

Vehicular Volume (VV) = 2427 veh/hr L_{CIA} = 38.4 m (126.0 ft)

$$\text{Overall Crossing Compliance Rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{47}{118} = 39.8\%$$

Total Pedestrian Volume in the Crosswalk Area = 108 * 2 = 216 peds / hr

Total Pedestrian Volume in the Crosswalk Influence Area = 118 * 2 = 236 peds / hr

Spatial Compliance Rate = 86.44% Violation of flashing red signal = 9.09%

Temporal Compliance Rate = 44.55%

4- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	29	10	1	40

Jaywalkers from west side of the crosswalk = 6 peds in 30 min

Jaywalkers from east side of the crosswalk = 7 peds in 30 min

Total pedestrians in the Crosswalk Area = 29 + 10 = 39 peds in 30 min

Total pedestrians in the Crosswalk Influence Area = 40 + 6 + 7 = 53 peds in 30 min

Vehicular Volume (VV) = N/A L_{CIA} = 97.85 m (312.0 ft)

$$\text{Pedestrian Crossing Compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{29}{53} = 54.7\%$$

Total Pedestrian Volume in the Crosswalk Area = 39 * 2 = 78 peds / hr

Total Pedestrian Volume in the Crosswalk Influence Area = 53 * 2 = 106 peds / hr

Figure 3.6. Sample data summary sheet for signalized and unsignalized intersection crosswalks

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3.4. Analysis and Results

Analysis and results are organized in three subsections: 1. pedestrian crossing compliance rates (PCCR) in the study crosswalks, 2. observed flows on pedestrian paths leading to the crosswalks, and 3. effects of crosswalk features on crossing compliance rates.

3.4.1. Pedestrian Crossing Compliance Rates (PCCR)

Equation 3.2 was used to calculate the spatial crossing compliance rates (SCCR) for each crosswalk location and the data collection session. In addition, Equations 3.3 and 3.4 were applied to the signalized crosswalks to determine the temporal and the overall crossing compliances. Average pedestrian crossing compliance rates by location were then calculated for every crosswalk location and crosswalk type. Four crosswalk types were considered as mentioned before, i.e., marked and non-striped midblock crosswalks, and signalized and unsignalized intersection crosswalks. The crosswalks were compared with respect to the average crossing compliance rates. The results in the following sections are organized by crosswalk type. Descriptive statistics of the pedestrian crossing compliance rates are presented and discussed in the following paragraphs. Such statistics include the number of data collection sessions at each location, the range of compliance rates obtained for the location (i.e., min and max PCCR), the average pedestrian compliance rate at the location for all sessions (mean PCCR), the 85th percentile, and the standard deviation of the mean. Also, average pedestrian crossing compliance rates by section were obtained and reported by averaging pedestrian compliance rates over all locatio

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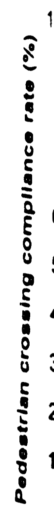

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locations of the same crosswalk type within the study section. Finally, the average pedestrian compliance rates for the entire study site were calculated.

3.4.1.1. Marked Midblock Crosswalks (MMCW)

Equation 3.2 was applied to calculate the pedestrian crossing compliance rates with crossing location for all the four marked midblock crosswalks in the study site for each data collection session. The results are summarized in Figure 3.7.

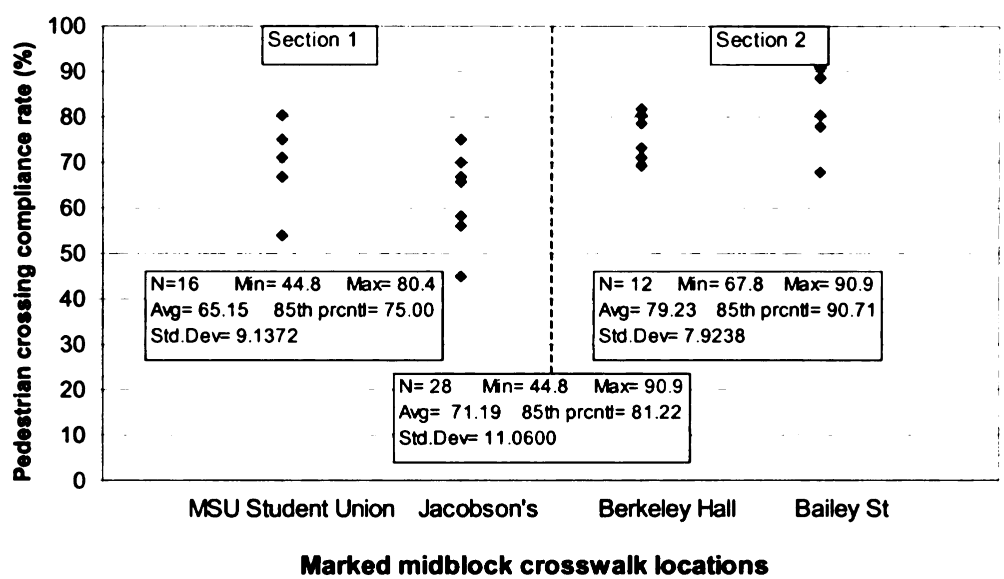
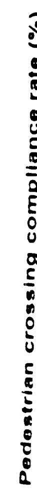


Figure 3.7. Pedestrian crossing compliance rates of all the marked midblock crosswalks--all data collection sessions

Figure 3.8 gives an example of the pedestrian crossing compliance rate variation at the marked midblock crosswalk in front of the MSU Student Union.



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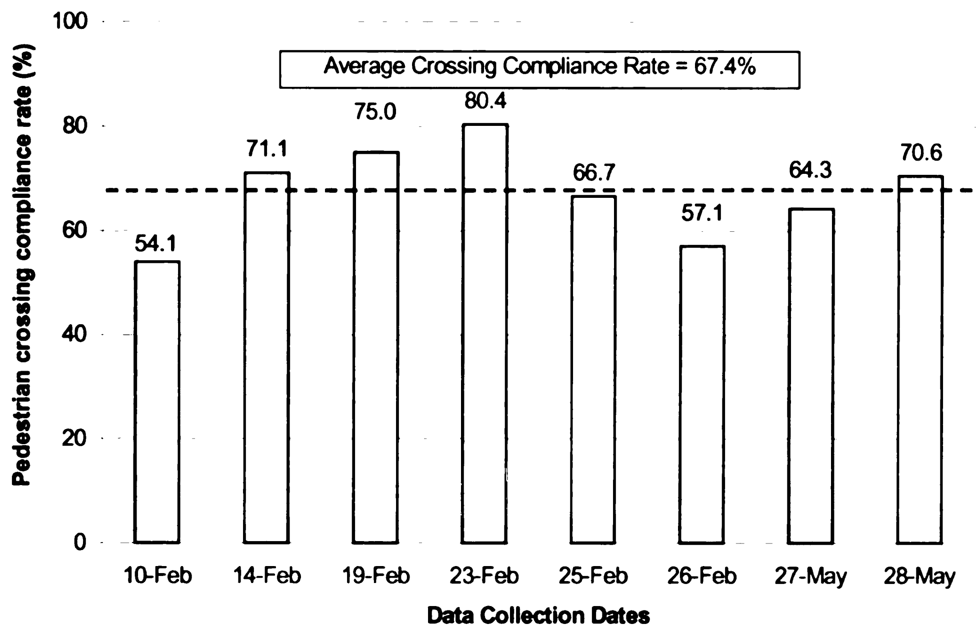

Figure 3.8. Pedestrian crossing compliance rates--MSU Student Union marked midblock crosswalk

Similar graphs for all the other marked midblock crosswalk locations are provided in Appendix B. Descriptive statistics of the pedestrian crossing compliance rates at the marked midblock crosswalks studied are provided in Table 3.3. The mean pedestrian compliance rates varied from 62.9% to 82.7% with an overall average value of 71.19%. Also, based on Table 3.3, the average crossing compliance rate at study section 2 is 79.23%, or 21.6% higher than that observed at study section 1.

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Table 3.3. Descriptive statistics of the pedestrian crossing compliance rates--all the marked midblock crosswalks

Study Section	Crosswalks	No of sess	PCCR (%)					Mean & (85^{th} prcntl) PCCRs for sections
			Min	Max	Mean	85^{th} prcntl	Std. Dev.	
1	Student Union	8	54.1	80.4	67.41	78.51	8.8137	65.16
	Jacobson's	8	44.8	75.0	62.90	73.25	9.4862	(75.00)
2	Berkeley Hall	6	69.4	81.6	75.75	81.55	5.1259	79.23
	Bailey St	6	67.8	90.9	82.70	90.89	9.1128	(90.71)
	Total:	28					Overall mean:	71.19

3.4.1.2. Non-striped Midblock Crosswalks (NSMCW)

Pedestrian crossing compliance rates for the two non-striped midblock crosswalks in the study section were calculated for each data collection session using Equation 3.2. The results are displayed in Figure 3.9.

Pedestrian crossing compliance rates at the non-striped midblock crosswalks varied from 58.3% to 69.0% with an average value of 64.2%. Figure 3.10 gives an example of the pedestrian compliance rate variation at the second non-striped midblock crosswalk. A similar graph for the first non-striped midblock crosswalk is provided in Appendix C. Descriptive statistics of the pedestrian crossing compliance rates at both non-striped midblock crosswalks in the study site are provided in Table 3.4. In order to answer the question of whether or not pedestrians complied with the two non-striped crosswalks differently, *t*-test was performed using the compliance data. The test resulted with the *t*-value of –0.538

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and the significance level of 0.614. The difference between the average values of the compliance rates is not statistically significant at the confidence level of 95% (0.614 > 0.05). Therefore, the null hypothesis that the pedestrian crossing compliance rates are not different at the non-striped midblock crosswalks is not rejected.

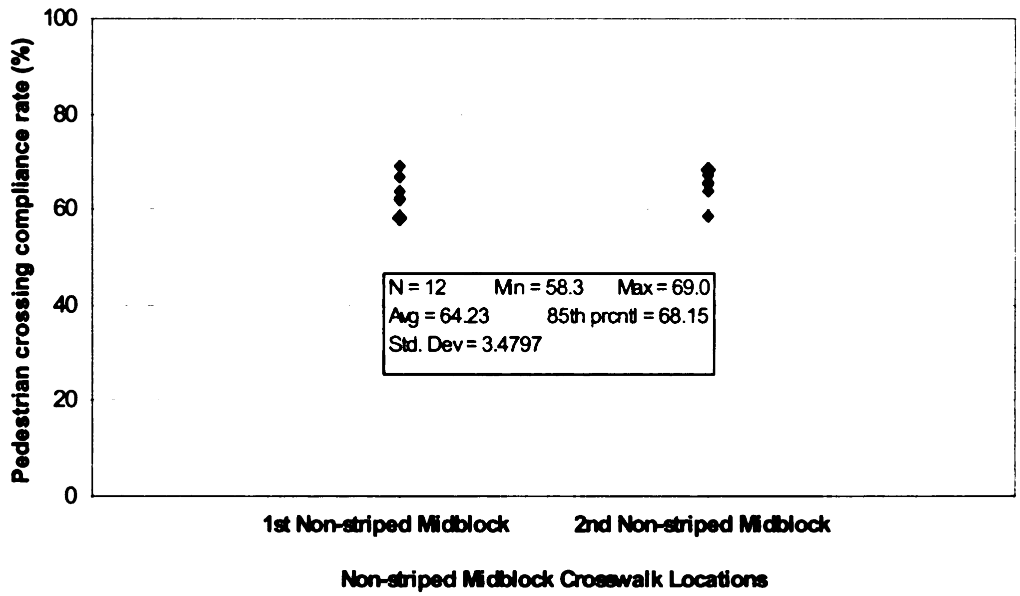

Figure 3.9. Pedestrian crossing compliance rates of all the non-striped midblock crosswalks--all data collection sessions

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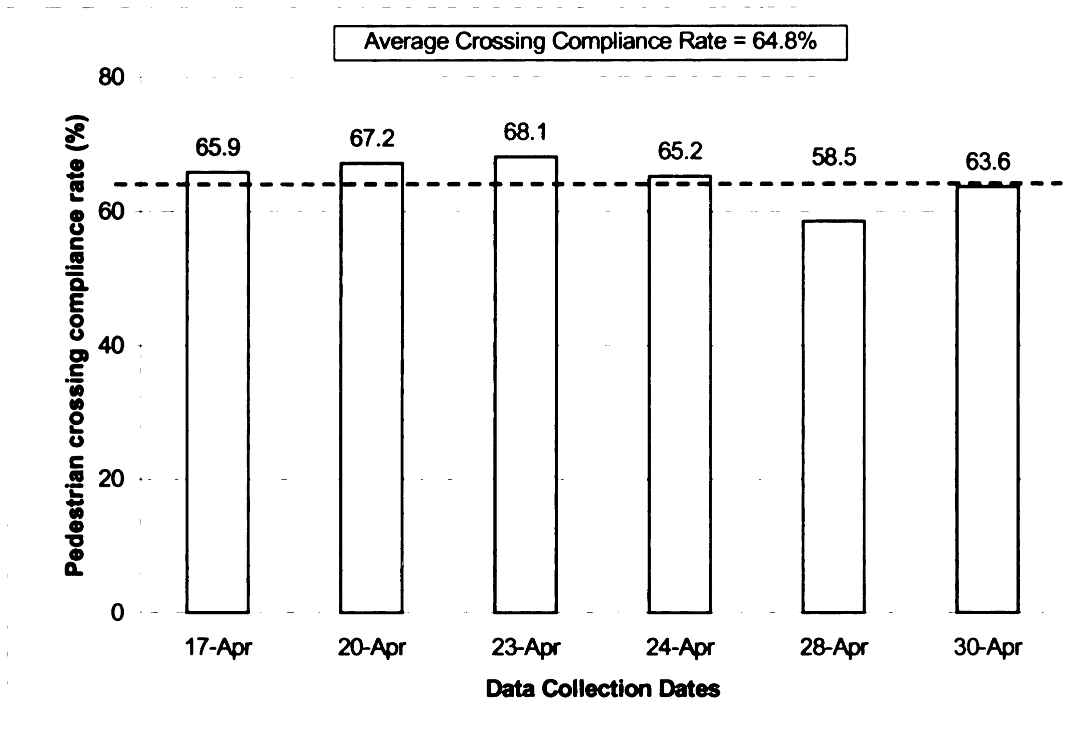

Figure 3.10. Pedestrian crossing compliance rates--2nd non-striped midblock crosswalk

Table 3.4. Descriptive statistics of the crossing compliance rates--both non-striped midblock crosswalks

Study Section	Crosswalks	No of sess	PCCR (%)					Mean & (85th prcntl) PCCRs for sections
			Min	Max	Mean	85th prcntl	Std. Dev.	
2	Non-striped 1	6	58.3	69.0	63.70	68.89	3.777	64.23
	Non-striped 2	6	58.5	68.1	64.75	68.06	3.439	(68.15)
	Total:	12					Overall mean:	64.23

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3.4.1.3. Unsignalized Intersection Crosswalks (USICW)

Pedestrian crossing compliance rates for the two unsignalized intersection crosswalks in the study site were calculated for each data collection session based on Equation 3.2. Each study section had only one unsignalized intersection crosswalk. The results obtained from the analysis are displayed in Figure 3.11. Pedestrian compliance rates at the unsignalized intersection crosswalks varied from 54.7% to 78.0% with an average value of 67.0%. Figure 3.12 offers an example of the pedestrian crossing compliance rate variation at the Charles Street unsignalized intersection crosswalk. A similar graph for the Orchard Street crosswalk location is provided in Appendix D.

Table 3.5 shows the descriptive statistics of the pedestrian crossing compliance rates at the unsignalized intersection crosswalks. The difference between the average values of the pedestrian compliance rates at the two unsignalized intersection crosswalks is not statistically significant at the 95% confidence level (*t*-value = -0.177, and significance level = 0.867 > 0.05). Therefore, the null hypothesis that the pedestrian crossing compliance rates at the two unsignalized intersection crosswalks do not differ is not rejected.

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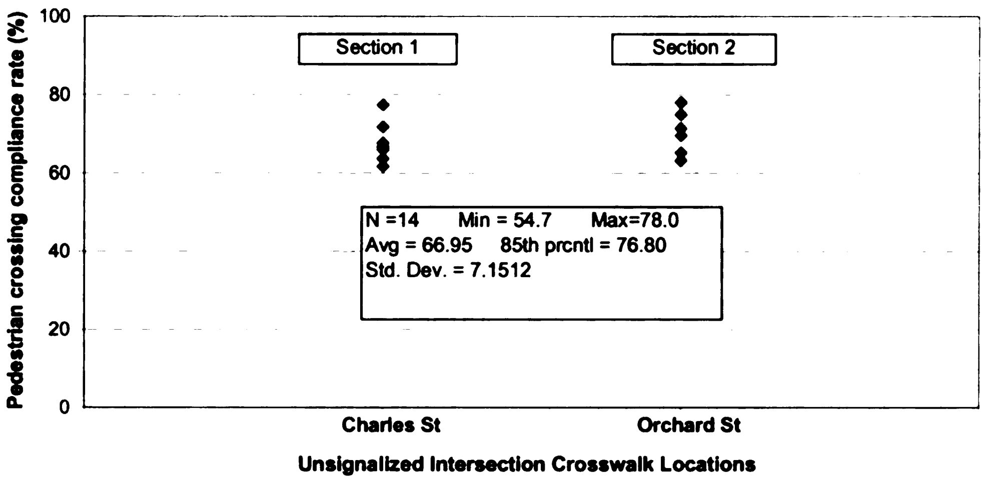

Figure 3.11. Pedestrian crossing compliance rates of all the unsignalized intersection crosswalks--all data collection sessions

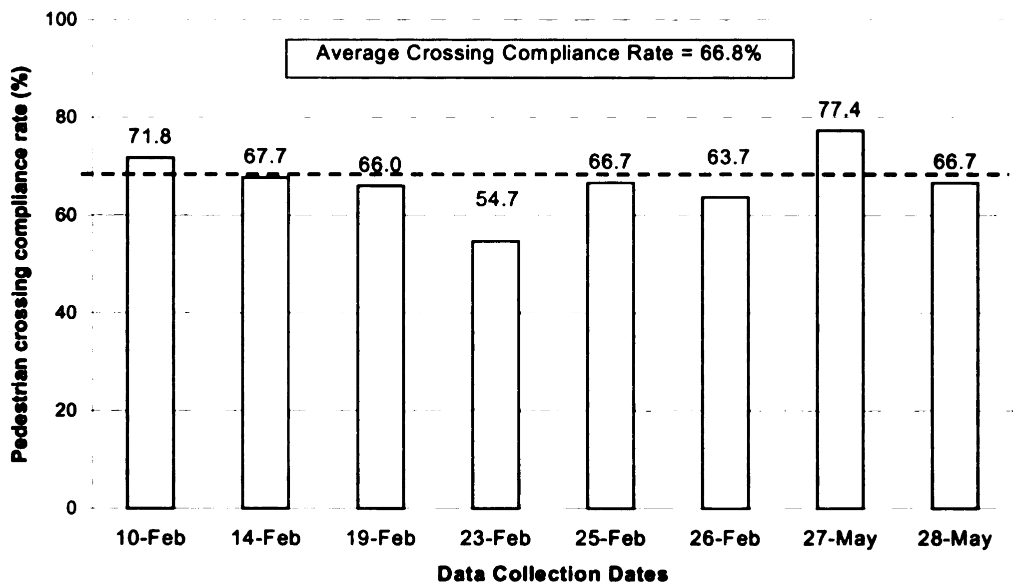

Figure 3.12. Pedestrian crossing compliance rates--Charles St unsignalized intersection crosswalk

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Table 3.5. Descriptive statistics of the crossing compliance rates--all the unsignalized intersection crosswalks

Study Section	Crosswalk	No of sess	PCCR (%)					Mean & (85th prcntl) PCCRs for Sections	
			Min	Max	Mean	85th prcntl	Std. Dev.		
1	Charles St	8	54.7	77.4	66.84	75.44	6.490	66.84	(75.44)
2	Orchard St	6	55.6	78.0	67.10	77.85	8.599	67.10	(77.85)
	Total:	14					Overall mean:	66.95	(76.80)

3.4.1.4. Signalized Intersection Crosswalks (SICW)

Spatial, temporal and overall crossing compliance rates for the five signalized intersection crosswalks in the study site were calculated for each data collection session. First, Equation 3.2 was applied to calculate the spatial compliance rates. Then, Equations 3.3 and 3.4 were used to calculate the timewise and the overall crossing compliance rates, respectively. Overall compliance rates reflected the pedestrian compliance with the crossing location and the pedestrian WALK signal indication simultaneously. The results are summarized next.

3.4.1.4.1. Spatial Crossing Compliance Rates (SCCRs) at the SICWs

As Figure 3.13 shows, pedestrian spatial crossing compliance rates at the signalized intersection crosswalks varied from 68.4% and 98.2% with an average value of 83.1%. Figure 3.14 gives an example of the pedestrian compliance rate variation at the Abbott St signalized intersection crosswalk. Similar graphs for all other signalized intersection crosswalk locations are provided in Appendix E.

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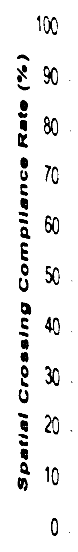

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The descriptive statistics of the spatial crossing compliance rates (SCCR) at all the signalized intersection crosswalks are summarized in Table 3.6. The mean values SCCRs for sections 1 and 2 are 82.78% and 83.40%, respectively. Overall, 83.13% of pedestrians crossing in the signalized intersection crosswalk influence areas complied with the crossing location. *T*-test resulted in the *t*-value and the significance level of −1.666 and 0.117, respectively. Therefore, the null hypothesis that pedestrians do not comply with the location of the signalized intersection crosswalks differently throughout the study section cannot be rejected. This shows that the signalized crosswalks are equally attractive and strategically located since they are equally well marked and recognized by pedestrians throughout the study site.

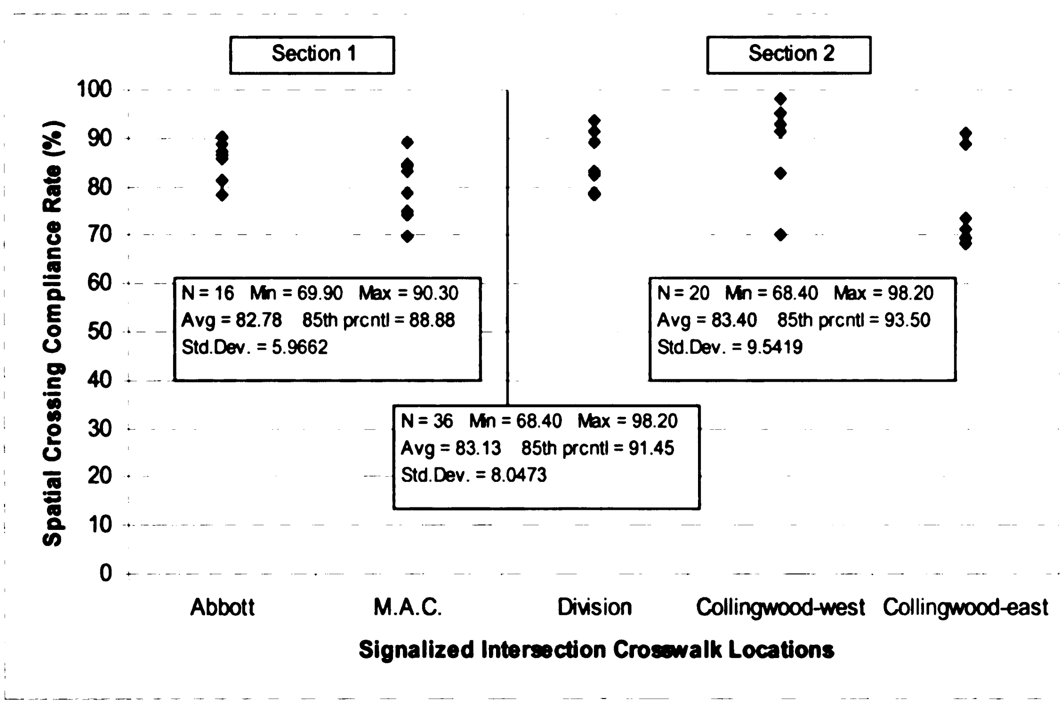
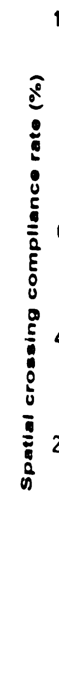


Figure 3.13. Spatial crossing compliance rates of all the signalized intersection crosswalks--all data collection sessions



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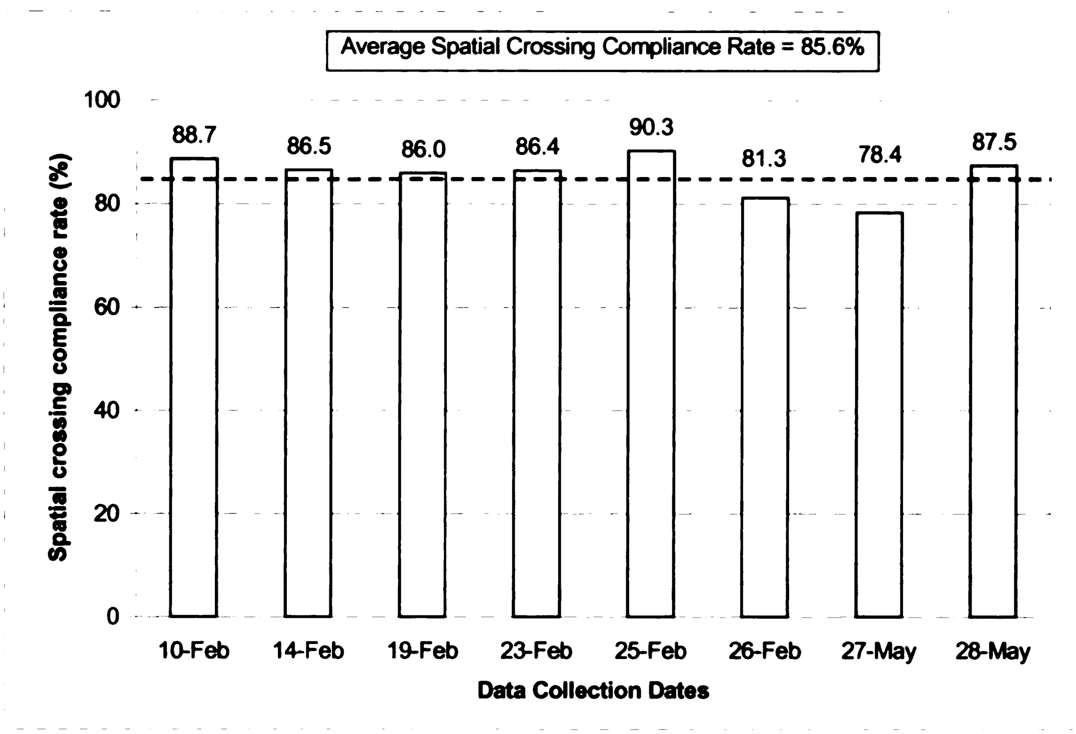

Figure 3.14. Spatial crossing compliance rates--Abbott St signalized intersection crosswalk

Table 3.6. Descriptive statistics of the spatial crossing compliance rates--all the signalized intersection crosswalks

Study Section	Crosswalks	No of ses	SCCR (%)					Mean & (85th prcntl) SCCRs for Sections
			Min	Max	Mean	85th prcntl	Std. Dev	
1	Abbott	8	78.4	90.3	85.64	89.74	3.914	82.78
	M.A.C.	8	69.9	89.1	79.93	87.60	6.497	(88.88)
2	Division	8	78.2	93.6	84.41	92.87	6.213	
	Collingwood-W	6	70.0	98.2	88.38	98.04	10.380	83.40
	Collingwood-E	6	68.4	91.2	77.07	91.90	10.228	(93.50)
	Total:	36					Overall mean:	83.13

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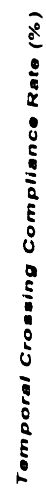

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3.4.1.4.2. Temporal Crossing Compliance Rates (TCCRs) at the SICWs

Temporal crossing compliance rates at the signalized intersection crosswalks were calculated using Equation 3.3. Such rates give information about the crossing compliance with the pedestrian signal only. Low rates may be an indication of a need to modify signal timing and/or phasing plans.

As Figure 3.15 shows, temporal pedestrian compliance rates in the signalized intersection crosswalks varied from 24.1% to 73.5% with an average of 50.63%. Figure 3.16 presents an example of the variation of the pedestrian compliance rate in the Abbott signalized intersection crosswalk. Similar graphs for all the other signalized crosswalks are provided in Appendix F.

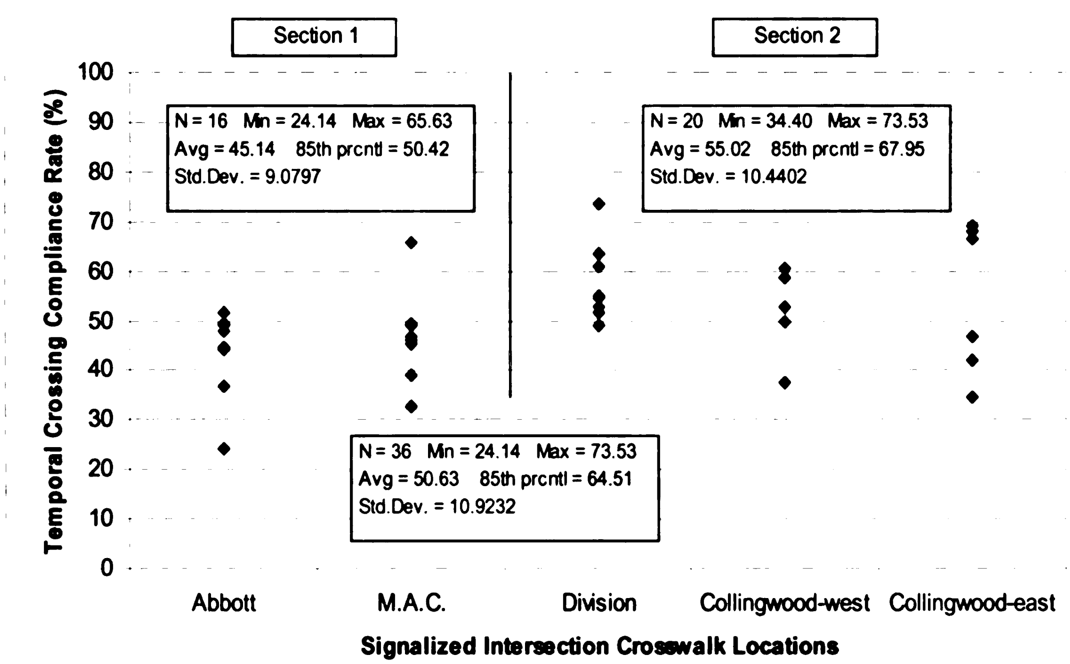

Figure 3.15. Pedestrian temporal crossing compliance rates of all the signalized intersection crosswalks--all data collection sessions

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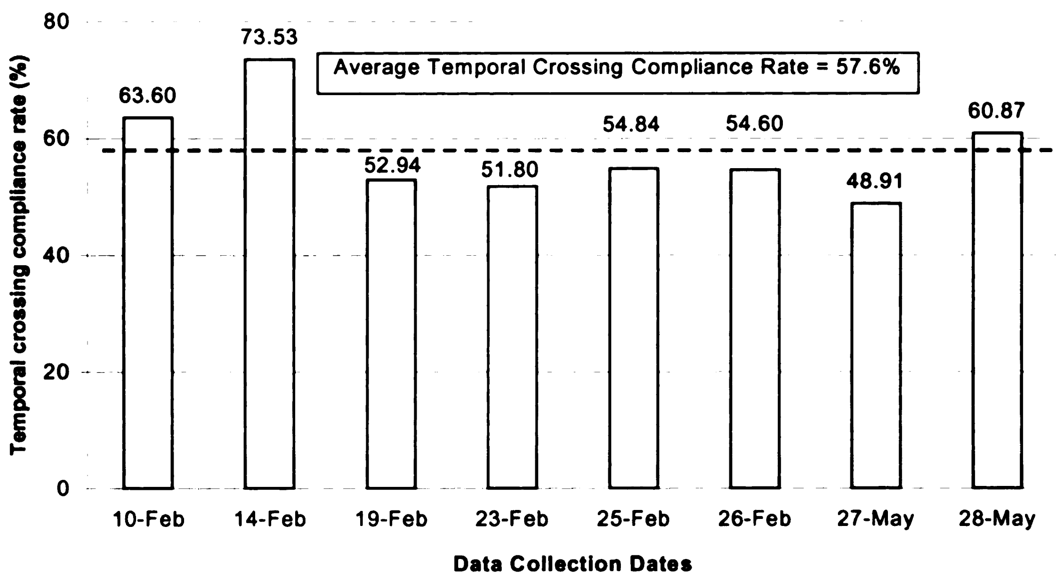

Figure 3.16. Pedestrian temporal crossing compliance rates--Division St signalized intersection crosswalk

The descriptive statistics of the temporal crossing compliance rates (TCCR) in all the signalized intersection crosswalks studied are summarized in Table 3.7. The mean values of TCCRs for sections 1 and 2 are 45.14% and 55.02%, respectively. Overall, 50.63% of pedestrians crossing in signalized intersection crosswalk areas complied with the pedestrian "WALK" signal. As shown in Table 3.7, the average temporal compliance rate in study section 2 is 21.9% higher than that in study section 1. The *t*-value and significance level obtained from the *t*-test are –22.63 and 0.039, respectively. Therefore, the null hypothesis that pedestrians do not comply with the WALK signal differently between the two study sections is rejected since the difference between the two cc

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compliance data sets is statistically significant at the confidence level of 95% (0.039 < 0.05).

Table 3.7. Descriptive statistics of the temporal crossing compliance rates-- all the signalized intersection crosswalks

Study Section	Crosswalks	No of ses	TCCR (%)					Mean & (85th prcntl) TCCRs for Sections
			Min	Max	Mean	85th prcntl	Std. Dev	
1	Abbott	8	24.1	51.5	43.37	50.80	9.020	45.14
	M.A.C.	8	32.8	65.6	46.80	60.00	9.432	(50.42)
2	Division	8	48.9	73.5	57.64	70.05	7.999	
	Collingwood-W	6	37.5	60.7	52.05	60.62	8.214	55.02
	Collingwood-E	6	34.4	69.2	54.51	69.18	15.338	(67.95)
Total:		36	Overall mean:					50.63

The average temporal crossing compliance in the study site is 50.6%, i.e., half of the pedestrians observed within the crosswalks complied with the pedestrian WALK signal. In fact, this figure is not bad at all because the cross streets (Abbott, M.A.C, Division and Collingwood) receive only about 36% of the green time (see Table 4.2 in Chapter 4). If the arrival pattern of pedestrians is assumed to be random with respect to the start of the pedestrian WALK interval, only about 36% of the pedestrians are expected to cross the street during the WALK interval. However, when some pedestrians arrive the street during the pedestrian DON'T WALK interval, they cannot cross the street even if they wish to because vehicles are moving in the east-west direction. Therefore, the rate of signal compliers is expected to be a little bit higher than 36%. The observed sig

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signal compliance (50.6%) is found to be higher than the expected one under the existing signal design in Grand River Avenue.

3.4.1.4.3. Overall Crossing Compliance Rates (OCCRs) at the SICWs

Overall crossing compliance rates at the signalized intersection crosswalks were calculated using Equation 3.4. Such rates give useful information about the overall compliance of pedestrians at the signalized intersections, with respect to both crossing location and signal indication. As Figure 3.17 shows that the overall pedestrian crossing compliance rates at all the signalized intersection crosswalks varied from 20.5% to 60.7%, with an average of 42.98%. An example of the overall pedestrian compliance rate variation at the Collingwood-E signalized intersection crosswalk is given in Figure 3.18. Similar graphs for all the other signalized intersection crosswalk locations are provided in Appendix G.

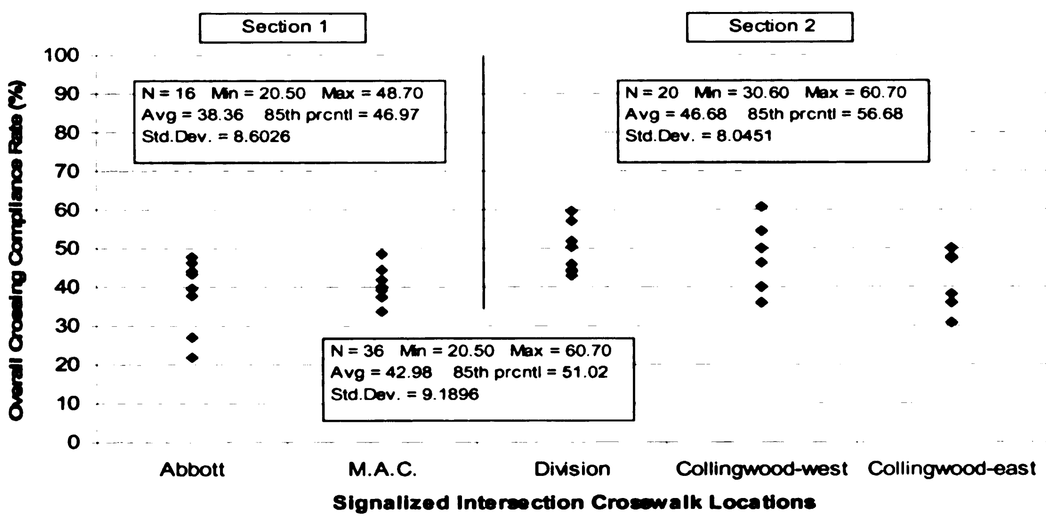

Figure 3.17. Pedestrian overall crossing compliance rates of all the signalized intersection crosswalks--all data collection sessions

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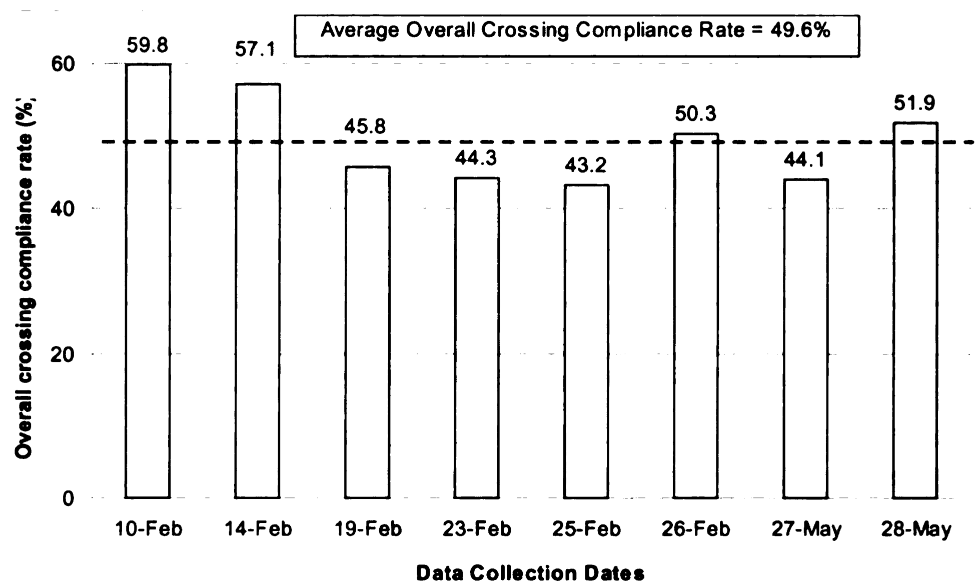

Figure 3.18. Pedestrian overall crossing compliance rates--Division St signalized intersection crosswalk

Table 3.8 presents the descriptive statistics of the overall crossing compliance rates at the signalized intersection crosswalks. According to Table 3.8, the average overall pedestrian compliance rate at study section 2 is 21.7% higher than that obtained from study section 1. *T*-test was performed to test if the difference between the average overall compliance rates of the two sections is statistically significant. The *t*-value and significance level obtained were -2.993 and 0.009, respectively. The difference is statistically significant at the confidence level of 95% (0.009<0.05). Therefore, overall, pedestrians comply with the signalized intersection crosswalks differently between the two sections of the s

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study site due to primarily differences in temporal crossing compliance between the two sections.

Table 3.8. Descriptive statistics of the overall crossing compliance rates--all the signalized intersection crosswalks

Study Section	Crosswalks	No of ses	OCCR (%)					Mean & (85th prcntl) OCCRs for Sections
			Min	Max	Mean	85th prcntl	Std. Dev	
1	Abbott	8	21.9	47.9	38.50	47.31	9.324	38.36
	M.A.C.	8	20.5	48.7	38.21	47.23	8.462	(46.97)
2	Division	8	43.2	59.8	49.56	58.86	6.322	46.68
	Collingwood-W	6	36.0	60.7	47.90	60.38	9.116	
	Collingwood-E	6	30.6	50.0	41.62	49.88	7.813	(56.68)
	Total:	36					Overall mean:	42.98

Comparison of the compliance rate analysis results obtained for the signalized intersection crosswalks shows that the compliance with the crossing location at the signalized crosswalks is very high (average value = 83.13%) while compliance with the pedestrian WALK signal indication (temporal compliance) is low with an average value of 50.63%. Pedestrian overall crossing compliance (spatial and temporal combined) is also low with an average value of 42.98%. In other words, the signalized intersection crosswalks in the study site appear to attract pedestrians as crossing points because they are clearly visible and strategically located. However, they fail to convince the majority of pedestrians to cross during the pedestrian WALK interval. One possible explanation for this practice relates to the low vehicular volumes during some periods of the day an

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and/or vehicles platooning with long gaps between platoons. These conditions offer pedestrians a motive and an opportunity to cross safely during the pedestrian DON'T WALK interval. The non-compliance of pedestrians with the WALK signal indication may also be linked to improper signal timing and/or signal phasing design. An in depth analysis of these issues is beyond the scope of the subject study as a variety of phasing data is not available for consideration.

3.4.2. Observed Flows on Pedestrian Paths Leading to the Crosswalks

Pedestrian flows were observed on paths leading to the study crosswalks in order to get more information about pedestrians' origins and destinations, i.e., where pedestrians come from and where they cross through the study section. Figures 3.19.a and b show the schemes of study sections 1 and 2, respectively, with the volumes on the crosswalks and pedestrian paths. The first number on the paths represents the number of pedestrians that crossed the street with or without using the crosswalks, and the second one indicates the total pedestrian volume on the pedestrian paths.

Figures 3.19.a and b also show the position of barriers on the median and the sidewalks, which are expected to divert people from crossing at non-designated locations and channelize pedestrian flow to designated crossing locations. Determination of the magnitude of the effects of barriers on the crossing compliance was not possible because the barriers were placed irregularly. In addition, in many locations the barriers were placed between sidewalks and paths and were usually ineffective to prevent the jaywalking on

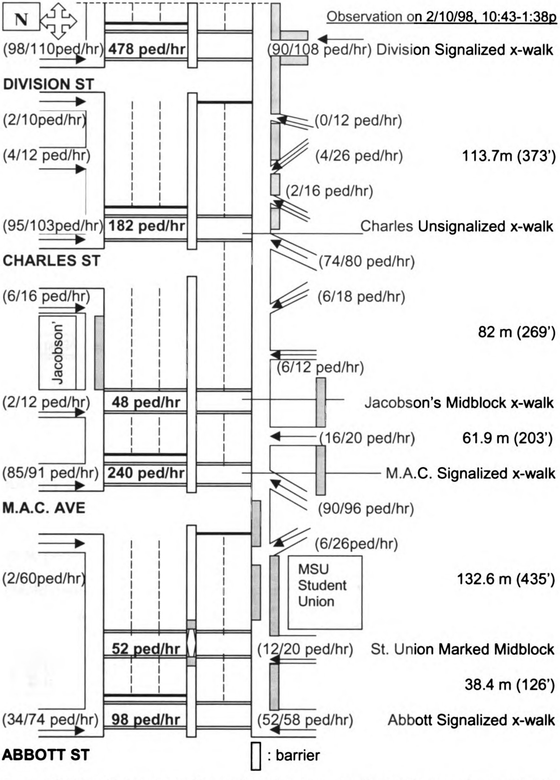

Figure 3.19.a. Volumes in the pedestrian crosswalks and paths in section 1

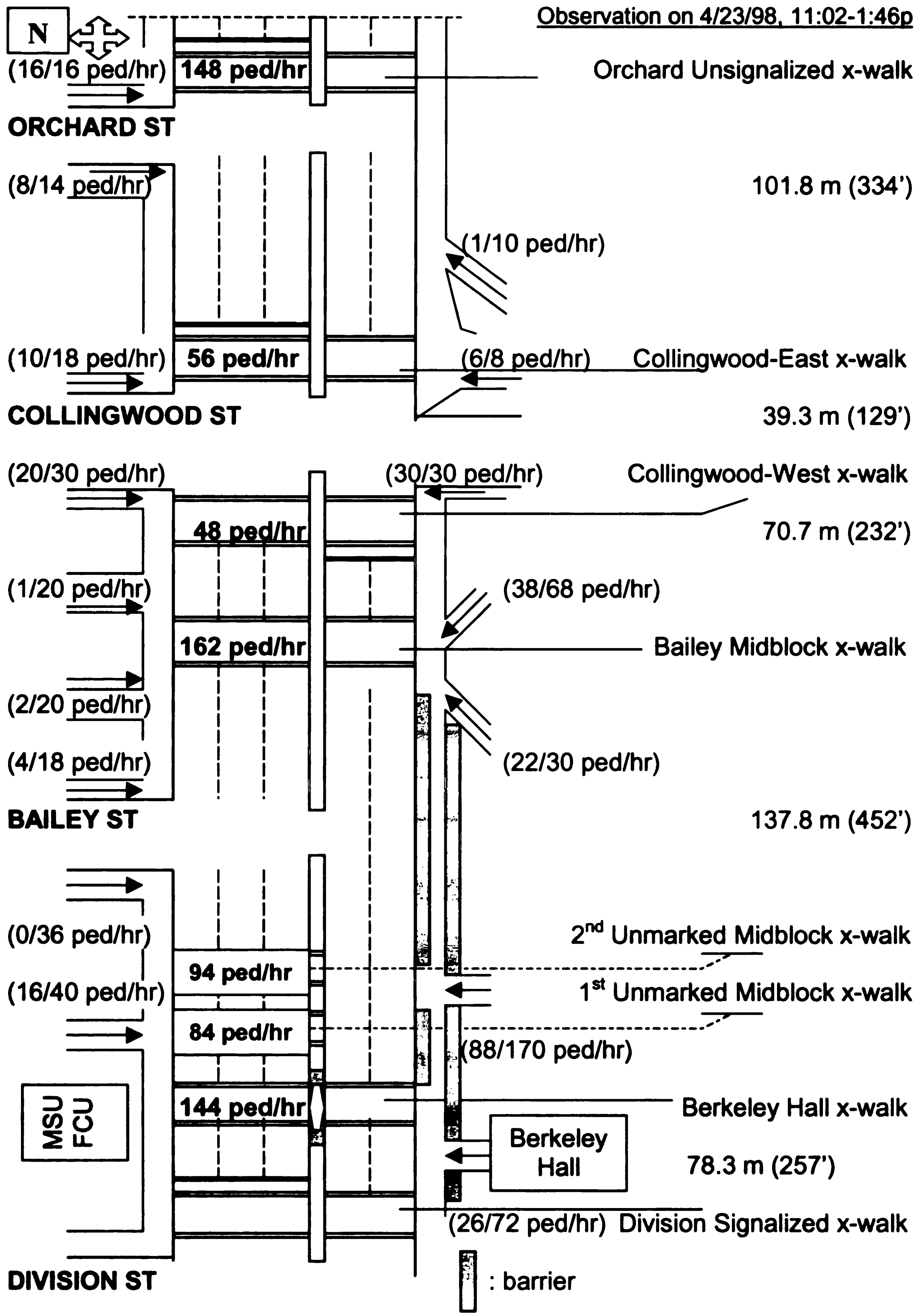

Figure 3.19.b. Volumes in the pedestrian crosswalks and paths in section 2

the median. On the median, there is no barrier installed except from flower boxes next to the median shelters. In section 2, long barriers are installed between the sidewalk and the roadway around the Berkeley Hall and Bailey midblock crosswalks. It is noticeable that the average crossing compliance is significantly higher at the Berkeley Hall and Bailey midblock crosswalks than those of the MSU Student Union and Jacobson's midblock crosswalks in section 1 that lacks barriers (see Table 3.9).

Table 3.9. Average observed crossing compliance rates at the marked midblock crosswalks

Study sections	Midblock crosswalks	Average observed crossing compliance rates (%)
1	MSU Student Union	67.4
	Jacobson's	62.9
2	Berkeley Hall	75.8
	Bailey St	82.7

3.4.3. Effects of Crosswalk Features on Crossing Compliance

In this section, the effects of various features of the crosswalks on pedestrian crossing compliance were analyzed. Such features include the presence of crosswalk stripes, shelters, and pedestrian signals. The null hypothesis used in the statistical analyses is that there is no difference between crosswalks with and without the specified feature with respect to the pedestrian crossing compliance rates.

3.4.3.1. Effect of Crosswalk Markings (Stripes) on Crossing Compliance

The effect of crosswalk stripes on pedestrian crossing compliance at the midblock crosswalks was assessed through statistical comparisons of the compliance rates between the marked and the non-striped midblock crosswalks in study section 2. Descriptive statistics of the crossing compliance rates are presented in Table 3.10.

As Table 3.10 demonstrates, the presence of markings at the crosswalks contributes to increased crossing compliance rates. An average pedestrian compliance rate of 79.2% was observed at the marked midblock crosswalks versus a rate of 64.2% at the non-striped ones. This observation was confirmed through the *t*-test which showed that the difference between the average values of the pedestrian crossing compliance rates at the two types of crosswalks was statistically significant at the confidence level of 95% (*t*-value = 7.999 and significance level = 0.000 <0.05).

Table 3.10. Descriptive statistics of the compliance rates--all the striped and non-striped midblock crosswalks

Study Section	Crosswalks	No of sess	PCCR (%)				
			Min	Max	Mean	85th prcntl	Std. Dev
2	Striped	12	67.8	90.9	79.23	90.71	7.929
	Non-striped	12	58.3	69.0	64.23	68.15	3.487
	Total:	24					

3.4.3.2. Effect of Median Shelters on Crossing Compliance

The MSU Student Union and Berkeley Hall midblock crosswalks have a shelter located at the median while the other marked midblock crosswalk locations do not. In addition to improvements in the esthetic of the corridor, such structures may increase the visibility of the midblock crosswalk locations for both drivers and pedestrians. The effect of the shelters on pedestrian spatial compliance was evaluated as follows.

A summary of the descriptive statistics on the pedestrian compliance rates for crosswalks with and without shelter are given in Table 3.11. The difference between the average values of the compliance rates at the two types of crosswalks is not statistically significant (t-value = -0.126 and significance level = 0.902 > 0.05). Therefore, the null hypothesis that the median shelters have no effect on pedestrian compliance rates is not rejected and thus, their use may be justified only as part of aesthetic improvements to a corridor, bu not as a means to increase of pedestrian safety.

Table 3.11. Descriptive statistics of the compliance rates--all the midblock crosswalks with and without shelter

Crosswalks	No of sess	PCCR (%)				
		Min	Max	Mean	85^{th} prcntl	Std. Dev
With shelter	14	54.1	81.6	70.99	80.48	8.383
Without shelter	14	44.8	90.9	71.39	90.15	13.557
Total:	28					

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3.4.3.3. Effect of Pedestrian Signal on Crossing Compliance

The effect of the presence of a pedestrian signal on pedestrian crossing compliance was also studied. The descriptive analysis of the crossing compliance rates for both types of crosswalks are given in Table 3.12. The difference between the average values of the compliance rates in the two types of crosswalks is statistically significant (*t*-value = 8.744 and significance level = 0.000 < 0.05). Therefore, the null hypothesis is rejected that the existence of a pedestrian signal has no significant effect on spatial crossing compliance rates at the intersection crosswalks.

Table 3.12. Descriptive statistics of the spatial crossing compliance rates-- all the signalized and unsignalized intersection crosswalks

Crosswalks	No of sess	PCR				Std. Dev
		Min	Max	Mean	85^{th} prcntl	
Signalized	36	68.4	98.2	83.13	91.45	8.047
Unsignalized	14	55.6	78.0	67.45	76.56	6.318
Total:	50					

Finally, Table 3.13 summarizes the results from the analysis of the pedestrian crossing compliance rates at the study crosswalks along the Grand River Avenue. Overall, the highest pedestrian crossing compliance rates were observed in the marked midblock crosswalks.

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Table 3.13. Descriptive statistics of the pedestrian compliance rates--summary of all the study crosswalks

Pedestrian Spatial Crossing Compliance Rates, SCCR (%)						
Crosswalks	No of Sess	Mean PCR	85^{th} prcntl	Std. Error	Std. Dev.	95% Conf. Interval
Non-striped midblock	12	64.23	68.15	1.007	3.487	62.009 – 66.441
Marked midblock	28	71.19	81.22	2.091	11.062	66.896 – 75.475
Unsignalized	14	66.95	76.80	1.911	7.151	62.821 – 71.079
Signalized	36	83.13	91.45	1.341	8.047	80.402 – 85.848
Pedestrian Overall Crossing Compliance Rates, OCCR (%)						
Signalized	36	42.98	51.02	1.532	9.190	39.871 – 46.090

In summary, pedestrians recognize and use the signalized intersection crosswalks properly with respect to their locations. The average observed spatial crossing compliance in the signalized crosswalks is 83.13%. However, pedestrians do not seem to be complying with the WALK signal as they comply with the location. The average overall crossing compliance in the signalized crosswalks is 42.98%. The marked midblock crosswalks are also favored by pedestrians with a high spatial compliance (71.19%). The unsignalized intersection crosswalks and the non-striped midblock crosswalks followed with the spatial crossing compliance rates of 66.95 and 64.23%, respectively.

3.5. Summary and Conclusions

In Chapter 3, the effectiveness of various crossing options was assessed through the study of pedestrian crossing activity along the corridor (Grand River

Avenue between Abbott and Bogue Streets). Comparisons were performed with respect to pedestrian compliance rates in the crosswalks. The main conclusions from these analyses are as follows:

- A positive type of traffic control increases pedestrian crossing compliance. The highest pedestrian spatial compliance rates were observed at the signalized intersection crosswalks (average PCR = 83.13%), followed by the marked midblock crosswalks (71.19%), and unsignalized intersection crosswalks (66.95%). The non-striped midblock crosswalks registered the lowest pedestrian compliance rate of 64.23%.
- Pedestrian spatial crossing compliance was greater at the midblock crosswalks than the unsignalized intersection crosswalks. Thus, when proper conditions exist (i.e., long links, land uses with significant pedestrian trip generations and attractions in midblocks), marked midblock crosswalks can be used with confidence as a large majority of pedestrians appear to recognize and use them properly.
- While markings and signals increase the pedestrian spatial crossing compliance, the midblock shelters on median do not seem to have an effect on pedestrian crossing compliance rates. Therefore, the use of the shelters as a means to increase the pedestrian crossing compliance is not confirmed.
- Overall pedestrian crossing compliance rates at the signalized intersection crosswalks is found to be low with an average value of 42.98%. This indicates that the majority of pedestrians crossing at the signalized

crosswalks violate the pedestrian WALK signal, probably especially during low vehicular traffic flow. The effect of signal timing and phasing schemes at the signalized intersections and the signal progression along the corridor should be studied in a future study and necessary adjustments can be done to encourage pedestrians to comply with the signals to increase pedestrian compliance as well as safety.

- Although it was not possible to determine the magnitude of the effect of the barriers on crossing compliance rates, it is noticeable that the spatial crossing compliance rates are higher at the midblock crosswalks in section 2 than those of the midblock crosswalks in section1. Section 2 has long barriers located between sidewalks and the roadway; on the other hand, section 1 lacks barriers.

3.6. Recommendations for Future Research

In Chapter 3 the procedures related to the evaluation of pedestrian crosswalks based on user compliance was described and the results were discussed. The data collected on a 1-km long urban boulevard were limited in terms of different pedestrian signal timing and phasing schemes. So, the effect of different signal timings and phasing plans on pedestrian compliance was not studied. A future research should address this issue, together with the effect of platoon progression and signal coordination on pedestrian compliance.

Chapter 4

OPERATIONAL ANALYSIS: MEASUREMENT, ESTIMATION, AND APPLICATION OF PEDESTRIAN CROSSING TIMES, AND PEDESTRIAN LEVEL OF SERVICE AT SIGNALIZED INTERSECTION CROSSWALKS

4.1. Introduction

Pedestrian crossing times are used in the determination of pedestrian level of service (LOS) of the signalized intersection crosswalks. The main measure of effectiveness used in the US to define the pedestrian level of service at signalized crosswalks is the average pedestrian space (*HCM*, 1997). This is a function of pedestrian crossing time and other parameters including crosswalk width, pedestrian crossing length, pedestrian volumes, length of pedestrian green signal indication, and behavioral characteristics. Moreover, pedestrian crossing times can assist in the proper selection of pedestrian signal timing settings.

A variety of methodologies have been developed for determining pedestrian crossing times at signalized intersections. The literature review indicates that the existing methodologies underestimate pedestrian crossing time (Virkler et al., 1995). Some of the methodologies do not consider pedestrian platoon and none of them considers two-way platoons. Therefore, a need has been identified to validate such methodologies with field data and discuss their strengths and limitations for application.

Field data collected on Grand River Avenue (M-43) between Abbott and Bogue Streets are used to validate the methodologies for the estimation of pedestrian crossing times during a vehicular off-peak period (10:30-1:30 pm) and

the PM-peak period (2:30-6:00 pm). Statistical tests are performed to test the performance of each study methodology. Summary results are presented and interpreted, along with recommendations for model improvements. Finally, measured pedestrian crossing times are used to evaluate crosswalk operations at the study intersections with respect to the pedestrian LOS and minimum signal timing settings.

4.2. Methodology

In determining the pedestrian level of service, the procedure described in Chapter 13 of the 1997 Highway Capacity Manual is utilized. The procedure is summarized in section 4.2.1.

To estimate pedestrian crossing times, several methodologies described in Chapter 2 are used and tested against the data collected at the Grand River Avenue signalized crosswalks. The validation of the existing formulae to estimate crossing times is described in section 4.2.2.

4.2.1. Pedestrian Level of Service (LOS) at Signalized Crosswalks

The "Pedestrians" Chapter of the 1997 Highway Capacity Manual (Chapter 13) uses the average space per pedestrian as the criterion for the pedestrian crosswalk level of service (LOS) estimation (*US HCM*, 1997). The average space per pedestrian, M_c, is defined as

$$M_c = TS / (V * T) \qquad Eq.4.1$$

where

M_c = average space per pedestrian (m^2/ped);

TS = crosswalk time-space available to pedestrians during one cycle (m^2-sec/cycle);

V = total incoming and outgoing pedestrians volume (ped/cycle), and

T = pedestrian crossing time (sec).

The crosswalk time-space, *TS*, available to pedestrians is calculated as

$$TS = W * L * G \qquad Eq.4.2$$

where

W = crosswalk width (m),

L = pedestrian crossing distance (m), and

G = walk interval (sec).

The pedestrian walk interval, *G*, is typically the sum of the pedestrian green and flashing red intervals (clearance interval) reduced by 3 sec to account for start-up delays due to pedestrian perception-reaction. A two-dimensional time-space diagram illustrating the approach described above is shown in Figure 4.1. If pedestrian crossing volumes and the required pedestrian crossing times are known, then the crosswalk level of service can be determined.

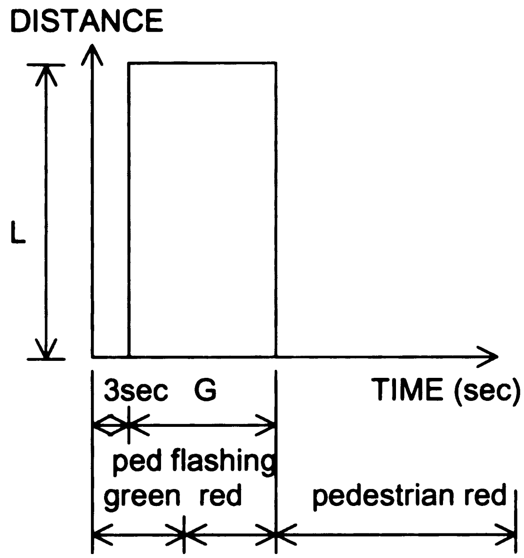

Figure 4.1. Time-space diagram for HCM approach

4.2.1.1. Pedestrian LOS for the Maximum Surge Condition

Equation 4.1 yields the pedestrian level of service (LOS) for average conditions during the WALK interval (pedestrian green and flashing red intervals). During some cycles, pedestrian volume reaches to its maximum level. These conditions should also be examined. Chapter 13 of the 1997 HCM offers a method to analyze the conditions in which the maximum number of pedestrians is in the crosswalk area. In this method, crosswalk flows (pedestrians per minute) are multiplied by the lengths of the DON'T WALK interval and the crossing time. The DON'T WALK interval is used to estimate the number of pedestrians queued when the WALK interval is given. The crossing time is added to estimate the number of new arriving pedestrians during the period that the queued pedestrians cross the street. The calculation of the LOS for the maximum surge condition is given as follows:

$$V_m = V.(DW + T)/60 \qquad Eq.4.3$$

$$M_S = W * L / V_m \qquad Eq.4.4$$

where

V_m = maximum number of pedestrians in a crosswalk,

V = pedestrian volume (ped/min),

DW = pedestrian red (DON'T WALK) interval (sec),

T = pedestrian crossing time (sec), and

M_S = average space per pedestrian for the maximum surge condition (m^2/ped).

4.2.1.2. Estimating the Decrement to LOS Due to Turning Vehicles

The time-space method described in Chapter 13 of the 1997 HCM estimates the decrement to the crosswalk level of service (LOS) due to the presence of turning vehicles. On the study site, Grand River Avenue between Abbott and Bogue Streets, at the signalized intersection crosswalks turning vehicles are allowed during the pedestrian WALK interval. Due to turning movements, it is expected that the average crosswalk LOS is reduced because turning vehicles preempt crosswalk space. This analysis is done by assuming an average area occupancy of a vehicle in the crosswalk. The decrement of LOS is calculated as the product of vehicle swept-path and crosswalk width, and an estimate of the time that the vehicle preempts this space. The swept-path for an average vehicle may be estimated assuming an average vehicle width of 2.44 m (8 ft) and a vehicle occupancy time of 2 sec. Under these assumptions, each turning vehicle will preempt a time-space of *(2.44 m x (crosswalk width) x 2 sec)* in m^2-sec/veh. If we know how many vehicles turn during an average green phase, the total decrement to an available time-space can be calculated. With calculated decrements in the available time-space, new crosswalk LOS can be determined.

In the following sections, the current methodologies for estimating the required pedestrian crossing time are evaluated. Pedestrian crossing times will be used in the calculation of crosswalk LOS.

4.2.2. Validation of Existing Methodologies to Calculate Pedestrian Crossing Time

Various models proposed for pedestrian crossing time estimation in the literature are validated using the measured pedestrian crossing time data collected from the study site. First, pedestrian crossing times are calculated based on the geometric characteristics of the signalized intersection crosswalks, provided in the next section for each signalized intersection crosswalk using the five alternative methodologies described in the literature review (Chapter 2). Then, the results obtained by each model for each location were compared with the measured pedestrian crossing times obtained by the field observations. Statistical tests were performed to determine whether or not predicted and measured pedestrian crossing times were different. Moreover, the results obtained for all the crosswalks, when testing the same model, are checked for consistency. Based on the results from the statistical analysis, an assessment of the effectiveness of a given model predicting pedestrian crossing time compared to the field data became possible.

4.3. Data Collection

The field data were collected on all the five signalized intersection crosswalks in the study site. These include geometric characteristics of the crosswalks, existing signal timing, pedestrian volume per cycle, and average pedestrian crossing time.

Table 4.1 summarizes geometric characteristics of the study crosswalks such as location identification, pedestrian crossing distance, and crosswalk width. Signal timings (WALK, clearance and DON'T WALK intervals, and cycle length) at the study crosswalks are presented in Table 4.2.

Table 4.1. Geometric characteristics of the signalized intersection crosswalks

Crosswalks	Crossing Length (m)	Crosswalk Width (m)
Abbott St	35.19	3.43
M.A.C. Ave	27.79	3.25
Division St	27.84	2.71
Collingwood-west	31.92	3.20
Collingwood-east	37.89	3.53

Pedestrian movement data were collected on a cycle-by-cycle basis including pedestrian volumes and crossing times. Average pedestrian volumes were then obtained by averaging the cycle-by-cycle data obtained over the total

Table 4.2. Signal timings at the signalized intersection crosswalks*

Intersections	Pedestrian WALK interval (sec)	Pedestrian clearance interval (sec)	Pedestrian DON'T WALK interval (sec)	Cycle length (sec)
Abbott	23 23 23	13 13 13	54 64 64	90 off-peak+ 100 am-peak 100 pm-peak
M.A.C.	21 25 25	10 10 10	59 65 65	90 off-peak 100 am-peak 100 pm-peak
Division	20 21 22	10 10 10	60 59 58	90 off-peak 100 am-peak 100 pm-peak
Collingwood E and W	23 23 23	14 14 14	53 63 63	90 off-peak 100 am-peak 100 pm-peak

*: Data obtained from MDOT Traffic and Safety Division, +:Vehicular traffic off-peak/peak periods

number of cycles observed. The average pedestrian volume data for the off-peak and the PM-peak conditions are summarized in Table 4.3.

Table 4.3. Average pedestrian volume data at the signalized intersection crosswalks

Signalized Crosswalks	Average pedestrian volume per cycle, V (ped/cycle)	
	During 30-min period within the vehicular traffic off-peak period	During 30-min period within the vehicular traffic PM-peak period
Abbott St	2.6	4.8
M.A.C. Ave	6.4	2.8
Division St	15.7	7.9
Collingwood-W	1.5	1.3
Collingwood-E	1.2	1.6

Pedestrian crossing times for each signalized intersection crosswalk were measured on a cycle-by-cycle basis through the observation of the behavior of a typical individual pedestrian either crossing alone or crossing in a platoon of pedestrians (more or equal to five pedestrians crossing together) in a crosswalk.

A typical pedestrian is defined as one that is waiting alone or in a platoon of pedestrians for the WALK signal indication at the curbside and starts crossing after the pedestrian signal turns green (an example is given in Figure 4.2). Pedestrian crossing time for the typical pedestrian is measured from the instant

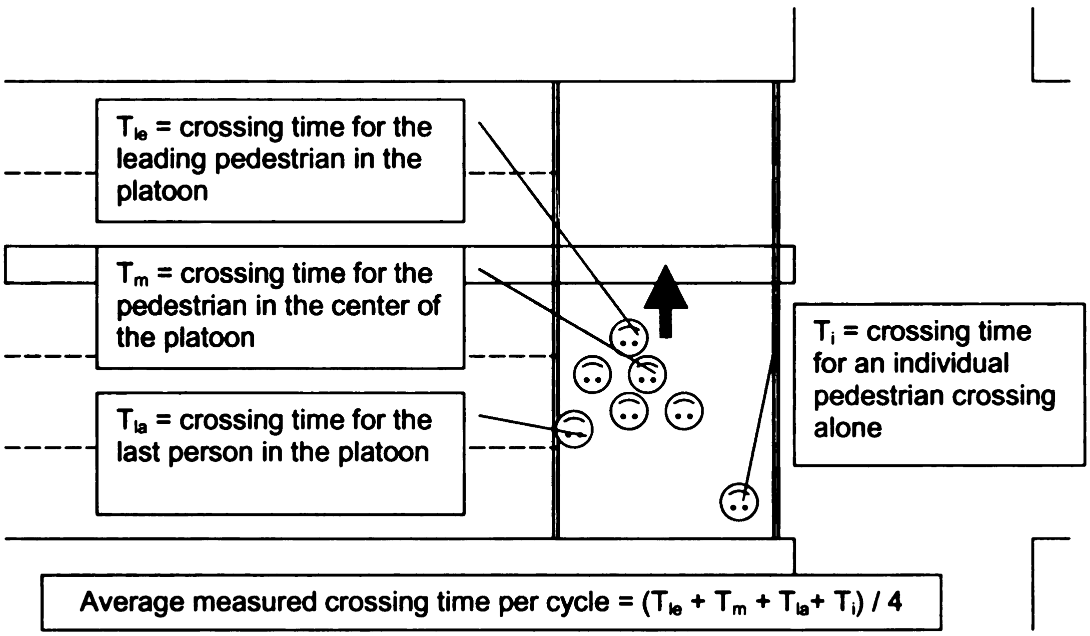

Figure 4.2. Calculation of average crossing time in the crosswalks

that the pedestrian signal turns green to the instant that the pedestrian reaches the opposite curbside. The leading, middle or last person is selected to represent the platoon movement.

The average pedestrian crossing times for each crossing location are obtained by averaging the cycle-by-cycle pedestrian crossing times (over the total number of cycles observed). The summary results are displayed in Table 4.4.

Table 4.4. Average measured pedestrian crossing times at the signalized crosswalks

Crosswalks	Average measured pedestrian crossing times, T (sec)			Flow rate (ped/hour)	Density (ped/m^2)	Pedestrian Speed (m/s)
	During off-peak period	During PM-peak period	Overall*			
Abbott St	20.5	21.2	21.6	137.8	1.14	1.63
M.A.C.	18.3	17.8	18.0	133.8	1.48	1.54
Division	19.0	19.6	19.2	320.5	4.25	1.45
Collingwood-west	19.8	19.9	19.9	50.7	0.50	1.60
Collingwood-east	23.6	23.2	23.3	51.7	0.39	1.63

*: Overall values include weekend data, too.

It should be noted that pedestrian crossing time does not only depend on the length of a crosswalk but also the density and/or the rate of pedestrian flow. Therefore, the crossing times in Table 4.4 for the two shortest crosswalks (MAC Ave and Division St crosswalks) do not have to be the same because the flow rate and density values are significantly different from each other. Division St crosswalk has the highest pedestrian flow rate and the highest density of all the crosswalks. In addition, this crosswalk has the shortest width of all. This means that the crosswalk has the lowest capacity or time-space available per pedestrian. The higher the density (or flow rate) is, the higher the number of interactions among pedestrians occurs. Therefore, high pedestrian density results in long crossing time and low crossing speed for a certain length.

The observed speeds are quite compatible with the findings in the literature. Knoblauch et al. (1996) reported minimum, maximum and average speeds of 1.38, 1.56 and 1.46 m/sec, respectively, for pedestrians who are younger than 65. In this study, the study population primarily belongs to the university community, who are supposedly more fit than the subject group in Knoblauch's study. Therefore, slightly higher average speeds are expected in the study crosswalks.

4.4. Analysis and Results

4.4.1. Validation of Existing Models to Estimate Pedestrian Crossing Time

Pedestrian crossing times were calculated for all the study intersections based on the following proposed methodologies:

- 1997 HCM, Chapter 13 (TRB, Report 209),
- 1997 HCM, Chapter 9 (TRB, Report 209),
- MUTCD Model (FHWA, USDOT,1994),
- Pignataro Model (Pignataro, 1973),
- ITE Model (ITE Committee, 1992), and
- Virkler -Guell Model (Virkler and Guell, 1984).

The formulations and assumptions involved in each methodology were presented in detail in Chapter 2. The Pignataro methodology yields two pedestrian crossing speed values, the larger of which refers to pedestrian crossing requirements of elderly pedestrians. The average of the two proposed values was used for comparison purposes.

The ITE and Virkler-Guell models require specification of the maximum pedestrian platoon size, *N* (one-directional platoon). The observed maximum pedestrian platoon sizes on signalized intersection crosswalks varied between 5 and 15 pedestrians. Maximum platoon size of 5 pedestrians was selected for the crosswalks of Collingwood Street, 7 for the crosswalk of M.A.C Avenue, 9 for the crosswalk of Abbott Street, and 12 for the crosswalk of Division Street based on field observations. Default values of speed (u=1.27 m/sec) and pedestrian headway (x=2.61 sec/ped/m of crosswalk width) were used in the Virkler-Guell model. These values correspond to LOS of B conditions. The results obtained from the model validation are presented in Table 4.5.

As Table 4.5 shows, the overall average measured pedestrian crossing time was used to perform the comparisons on an intersection-by-intersection basis. Collingwood Rd has two crosswalks. The east crosswalk had an average measured pedestrian crossing time of 23.3 sec and the west crosswalk had 19.9 sec. The higher of the two values (i.e., 23.3 sec) was used for comparison.

T-test was performed to determine whether the differences between the measured and the estimated average pedestrian crossing times are significant. The differences between measured and estimated crossing times were found statistically significant at the confidence level of 95% (t=12.137 and significance=

Table 4.5. Validation of the methodologies for pedestrian crossing time estimation

Model		Crosswalk	Estimated Pedestrian Crossing Time (sec)	Measured Pedestrian Crossing Time (sec)	Difference (sec)	Error %
HCM	Chp 13	Abbott	25.7	21.6	4.4	18.9
	Chp 9	Abbott	35.8	21.6	14.2	66.0
MUTCD Model		Abbott	32.8	21.6	11.2	52.1
Pignataro Model		Abbott	33.8 - 37.9+	21.6	12.2	56.5
ITE Model		Abbott	35.4	21.6	13.8	64.1
Virkler-Guell		Abbott	37.6	21.6	16.0	73.9
HCM	Chp 13	M.A.C.	20.3	18.0	2.3	12.7
	Chp 9	M.A.C.	29.8	18.0	11.8	65.4
MUTCD Model		M.A.C.	26.8	18.0	8.8	48.8
Pignataro Model		M.A.C.	27.8 - 31.0+	18.0	9.8	54.4
ITE Model		M.A.C.	28.6	18.0	10.6	58.8
Virkler-Guell		M.A.C.	30.5	18.0	12.5	69.5
HCM	Chp 13	Division	20.3	19.2	1.1	5.8
	Chp 9	Division	29.8	19.2	10.6	55.3
MUTCD Model		Division	26.8	19.2	7.6	39.7
Pignataro Model		Division	27.8 – 31.0+	19.2	8.6	44.5
ITE Model		Division	30.6	19.2	11.4	59.5
Virkler-Guell		Division	36.5	19.2	17.3	90.0
HCM	Chp 13	Collingwood	26.2	23.3++	2.9	12.4
	Chp 9	Collingwood	36.4	23.3	13.1	56.3
MUTCD Model		Collingwood	33.4	23.3	10.1	43.4
Pignataro Model		Collingwood	34.4 – 38.5+	23.3	11.1	47.6
ITE Model		Collingwood	34.4	23.3	11.1	47.7
Virkler-Guell		Collingwood	35.0	23.3	11.7	50.0

+: Statistical comparisons are based on the minimum of these two values. The higher value is for the elderly.

++: Average pedestrian crossing time on the eastside crosswalk (19.9 sec on the westside due to shorter crossing length)

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0.000). The analysis shows that all methodologies tested overestimate pedestrian crossing time, with the 1997 HCM (Chapter 13) methodology showing the closest fit (the difference between estimated and observed crossing times varied between 5.8 and 18.9%). These results were consistent across all the crosswalks when a particular model was evaluated, and across all the alternative models, when a particular intersection was studied.

The discrepancies between measured and estimated crossing times might be partly due to the age factor of the study population that mostly consists of college students who are physically more fit than an average person and may have less tolerance for delays to cross the street. Several other reasons can be cited in an attempt to describe the discrepancies between measured and estimated pedestrian crossing time values:

a. The default values of start-up delay and walking speed used in the existing methods for pedestrian crossing time estimation do not represent crossing characteristics of pedestrians using the study facilities. Indeed, field observations indicated that the start up delay (perception-reaction time) is about 3 sec. The models studied propose D values in the range of 3 to 7 sec. High D values cause the models overpredict. In addition, it was observed that average measured pedestrian walking speed in the study site was higher than the suggested walking speed utilized in the models (measured waking speed varied between 1.45 and 1.63 m/sec in the study site). When site specific and study population characteristics that impact pedestrian crossing time are not implemented in the formulae, it is not possible to estimate crossing time properly.

b. Some important variables are missing from the existing formulations. For example, presence of turning vehicles that share the same right-of-way with pedestrian traffic, two-directional crossing platoons, available crosswalk width, perceptual and kinetic characteristics of pedestrian users, weather conditions etc. may have an important effect on pedestrian crossing times at certain locations.

Findings from this analysis clearly demonstrate the need for further testing and refinement of the existing methodologies for pedestrian crossing time calculation in order to reflect more accurately actual conditions. Pedestrian crossing times can be used to:

a. provide information on proper signal timing for pedestrian signals, and
b. determine pedestrian LOS of signalized intersection crosswalks.

The results from these analyses are presented next.

4.4.2. Evaluation of Signal Settings

Measured pedestrian crossing times are used to evaluate existing signal settings during the vehicular traffic off-peak and the PM-peak periods. The duration of existing pedestrian green (WALK) and flashing red (DON'T WALK) signals is compared to minimum pedestrian crossing time criteria.

A proper selection of pedestrian WALK and flashing DON'T WALK times that allow for safe and comfortable crossing requires the minimum duration of

WALK and flashing DON'T WALK equal to the average crossing time of pedestrians who cross alone and/or in a platoon of pedestrians. A platoon of pedestrians is defined as more than five individuals crossing the street together. It is obvious that a platoon might require a longer crossing time due to restricted maneuvering ability in the platoon. Table 4.6 summarizes the results from the evaluation of the length of pedestrian WALK and flashing DON'T WALK intervals at the signalized intersection crosswalks.

The results in Table 4.6 show that the duration of pedestrian WALK and flashing DON'T walk intervals is sufficient to provide safe and comfortable crossing for pedestrians.

Table 4.6. Comparison of the length of pedestrian interval against the average measured pedestrian crossing times

Intersection Crosswalk	Vehicular Traffic off-peak Conditions		Vehicular Traffic PM-peak Conditions	
	Avg measured pedestrian crossing time (sec)	Existing pedestrian interval* (sec)	Avg measured pedestrian crossing time (sec)	Existing pedestrian interval* (sec)
Abbott	20.5	23+13	21.2	23+13
M.A.C.	18.3	21+10	17.8	25+10
Division	19.0	20+10	19.6	22+10
Collingwood -W	19.8	23+14	19.9	23+14
Collingwood- E	23.6	23+14	23.2	23+14

*: equals to the sum of WALK and flashing DON'T WALK times

Given the characteristics of the study population and safety considerations, using the 85th percentile of crossing time (instead of the average values) appears more appropriate for comparison purpose. In Table 4.7, the lengths of pedestrian interval (WALK and flashing DON'T WALK times) are compared against the 85th percentile values of crossing time.

According to Table 4.7, the length of pedestrian interval at all the locations is sufficient. Pedestrian clearance intervals (flashing DON'T WALK) should allow pedestrians who begin crossing just before the start of flashing red to reach a refuge point by the time the red indication is displayed. The median is considered as the refuge point for divided facilities and the opposite curb for undivided ones.

Table 4.7. Comparison of the length of pedestrian interval against the 85th percentiles of pedestrian crossing times

Intersection Crosswalk	85th percentile of the measured pedestrian crossing time (sec)	Minimum pedestrian interval (sec)
Abbott	25.0	36
M.A.C.	19.0	31
Division	21.0	30
Collingwood- W	25.0	37
Collingwood- E	22.0	37

To test if minimum pedestrian flashing red requirements are currently met, the available pedestrian flashing red time was compared to the time required for pedestrians to cross from curb to median. The latter was calculated by multiplying the measured pedestrian crossing time by the ratio of the distance between curb and median over the total crosswalk length. As the distances between the median and the north and south side curbs were typically not the same, the longer of the two was considered. The results from the comparison are displayed in Table 4.8. It is found that the clearance intervals currently used met the minimum flashing red interval criteria for pedestrian crossing needs at these locations.

Table 4.8. Evaluation of the length of existing clearance intervals

Intersection Crosswalks	Vehicular Traffic off-peak Conditions		Vehicular Traffic PM-peak Conditions	
	Average pedestrian crossing time to median (sec)	Clearance interval * (sec)	Average pedestrian crossing time to median (sec)	Clearance interval (sec)
Abbott	8.7	13	9.0	13
M.A.C.	7.8	10	7.4	10
Division	7.8	10	8.0	10
Collingwood -W	8.2	14	8.2	14
Collingwood- E	11.4	14	11.2	14

*: equals to the flashing DON'T WALK interval

4.4.3. Pedestrian LOS Estimation

Pedestrian levels of service at the signalized crosswalks was estimated using the procedure proposed by the 1997 HCM (Chapter 13). The LOS estimation is based on average space per pedestrian, M_c (m^2/ped). The latter is a function of the available time-space for pedestrians, TS (m^2-ped), the pedestrian crossing volume per cycle, V, and pedestrian crossing time, T (sec). The 85th percentile pedestrian crossing volume per cycle was used, instead of the average pedestrian crossing volume per cycle, since the variance of pedestrian volume from cycle-to-cycle was high. Measured pedestrian crossing time data were used and the walk interval, *G* (sec), involved in the estimation of *TS* was taken as the sum of the pedestrian green and clearance (flashing red) intervals reduced by 3 sec to account for start up delays due to pedestrian perception-reaction.

Pedestrian levels of service for the off-peak period are shown in Table 4.9. Under the conditions, all the signalized crosswalks operate at an acceptable LOS (B or better).

Table 4.9. Pedestrian level of service estimation--vehicular traffic off-peak conditions

Signalized Crosswalks	TS (m^2-sec)	M_c (m^2/ped)	LOS
Abbott	3983	48.58	A
M.A.C.	2529	15.35	A
Division	2037	5.28	B
Collingwood-W	3473	58.47	A
Collingwood-E	4308	91.26	A

Table 4.10 illustrates the pedestrian level of service estimations obtained for vehicular traffic PM-peak conditions. Examination of Table 4.10 indicates that all study signalized intersections operate at an acceptable pedestrian level of service during PM-peak pedestrian traffic conditions (LOS of B or better). The

high quality of service offered to pedestrians at the study signalized intersection crosswalks may explain the high crossing compliance rate at such locations as

Table 4.10. Pedestrian level of service estimation--vehicular traffic PM peak conditions

Signalized Crosswalks	TS (m^2-sec)	M_c (m^2/ped)	LOS
Abbott	3983	18.69	A
M.A.C.	2890	27.06	A
Division	2112	7.97	B
Collingwood-W	3473	63.46	A
Collingwood-E	4308	49.51	A

reported in Chapter 3. On the other hand, if a facility offers poor level of service to pedestrians, it is very likely that pedestrians will attempt to divert from the crosswalk or use it improperly. They typically do so by crossing at a different location (designated for crossing or not) or at the same location but at a different time (i.e., during pedestrian red interval if vehicle traffic gaps allow for crossing).

4.4.3.1. Calculation of Level of Service for the Maximum Surge Condition

Pedestrian crosswalk LOS is calculated also for conditions in which the maximum number of pedestrians is in the crosswalk. The LOS values for the vehicular traffic off-peak and the PM-peak conditions are given in Tables 4.11 and 12.

The LOS values presented in Tables 4.11 and 12 for the maximum surge condition did not differ from the ones calculated for average conditions during the pedestrian intervals. Therefore, the LOS of the crosswalks during the times is in the acceptable range (LOS of B or better) when the maximum number of pedestrians is in the crosswalk.

Table 4.11. Pedestrian level of service estimation for the maximum surge condition--vehicular traffic off-peak conditions

Signalized Crosswalks	V_m (pedestrians)	M_S (m^2/ped)	LOS
Abbott	2.03	59.52	A
M.A.C.	5.22	17.29	A
Division	13.39	5.64	B
Collingwood-W	1.30	78.43	A
Collingwood-E	1.23	103.37	A

Table 4.12. Pedestrian level of service estimation for the maximum surge condition--vehicular traffic PM-peak conditions

Signalized Crosswalks	V_m (pedestrians)	M_S (m^2/ped)	LOS
Abbott	5.77	20.93	A
M.A.C.	3.99	22.63	A
Division	8.69	8.68	B
Collingwood-W	1.10	92.80	A
Collingwood-E	1.53	83.06	A

4.4.3.2. Estimating the Decrement to LOS Due to Turning Vehicles

The decrement to LOS is calculated as the product of vehicle swept-path and crosswalk widths, and an estimate of the time that the vehicle preempts this space. It is assumed that each left- or right-turning vehicle will preempt a time-space of *(2.44m x W x 2 sec)* m^2-sec/veh in each cycle. The decrements to

Table 4.13. Decrements to crosswalk LOS due to turning vehicles-vehicular traffic off-peak conditions

Signalized Crosswalks	85^{th} percentile of pedestrian volume (ped/cycle)	85^{th} percentile of vehicle volume (veh/cycle)		Reduction to available TS (m^2-sec/cycle)		M_c (m^2/ped)	LOS
		RT	LT	RT	LT		
Abbott	4.00	0.65	1.18	10.88	19.75	48.39	A
M.A.C.	9.00	N/A*	N/A	N/A	N/A	15.35	A
Division	20.30	N/A	6.39	N/A	84.51	5.06	B
Collingwood-W	3.00	0.50	3.11	7.81	48.57	57.52	A
Collingwood-E	2.00	4.71	N/A	81.14	N/A	89.54	A

Table 4.14. Decrements to crosswalk LOS due to turning vehicles--vehicular traffic PM-peak conditions

Signalized Crosswalks	85^{th} percentile of pedestrian volume (ped/cycle)	85^{th} percentile of vehicle volume (veh/cycle)		Reduction to available TS (m^2-sec/cycle)		M_c (m^2/ped)	LOS
		RT	LT	RT	LT		
Abbott	10.05	2.28	2.44	38.16	40.84	18.32	A
M.A.C.	6.00	N/A*	N/A	N/A	N/A	27.06	A
Division	14.00	N/A	4.49	N/A	59.38	7.76	B
Collingwood-W	2.75	0.86	4.17	13.43	65.12	62.03	A
Collingwood-E	3.75	6.19	N/A	106.63	N/A	48.29	A

*N/A: not applicable

crosswalk LOS due to turning vehicles are presented in Tables 4.13 and 14 for the off-peak and PM-peak periods. According to the results presented in Tables 4.13 and 14, turning vehicles did not significantly affect the LOS at the study crosswalks.

4.5. Summary and Conclusions

In this chapter, pedestrian crossing times and quantitative level of service (LOS) estimations of crosswalks at the signalized intersections were studied in detail. Existing methodologies for the estimation of pedestrian crossing times were reviewed and summarized, and their limitations were discussed in Chapter 2. Here, these methodologies were validated using measured pedestrian crossing times. The data were collected at all the four signalized intersection crosswalks within the study area during the vehicular traffic off-peak and the PM-peak conditions. Moreover, measured pedestrian crossing time data were used to check if existing signal settings at the study intersections meet minimum green and flashing red requirements for pedestrians. Finally, measured pedestrian crossing times were used to assess the pedestrian LOS at all the signalized intersection crosswalks. The following conclusions were reached:

- The existing methodologies for pedestrian crossing time estimation systematically overpredicted pedestrian crossing times in the study site. Refinement of such methodologies is recommended so that they represent actual conditions in a more realistic manner.

- Pedestrian crossing time is a key measure to the evaluation of signal settings and the assessment of operational efficiency at signalized intersections from the perspective of pedestrian users.
- Pedestrian crossing times can assist in proper selection of signal settings, including pedestrian green and flashing red interval lengths. Therefore, pedestrian crossing times should be determined or estimated properly in order to design efficient signal timing for pedestrians as well as for vehicles.
- Overall the observed crossing speeds are compatible with the findings of other research studies.
- The lengths of the existing pedestrian interval (WALK and flashing DON'T WALK times) in the study site are sufficient to provide safe and comfortable pedestrian crossing at the signalized crosswalks. The minimum pedestrian clearance (flashing red) time criterion is met at all the locations, too.
- All the signalized intersection crosswalks in the study area operate at an acceptable pedestrian level of service (LOS B or better) during both the vehicular traffic off-peak and PM-peak conditions.
- Pedestrian levels of service in the study crosswalks under the maximum surge conditions did not differ from the ones obtained for average conditions during the WALK interval. Turning vehicles at the signalized intersections did not significantly affect the LOS values in the crosswalks.

4.6. Recommendations for Future Research

The research summarized in this part of the chapter focused on the validation of existing methodologies to estimate pedestrian crossing time and calculate pedestrian LOS at signalized crosswalks. All these methodologies overestimated observed crossing times at the signalized intersection crosswalks on Grand River Avenue. It is believed that the formulae overstate the length of the start-up delay (perception-reaction time) for pedestrians by choosing values from 4 sec to 7 sec. The field observations indicated that this value was in the range of 3 sec to 4 sec.

Secondly, none of the formulae considers two-way platoon movements. Consideration of two-way platoons is very important for the application of formulae in places where high bi-directional pedestrian volumes exist (such as in downtown New York City, Chicago, Seattle, etc.).

Thirdly, none of the formulae considers the effect of turning vehicles on individual pedestrians and platoons. All the formulae are valid under the conditions of little interaction between pedestrians and turning vehicles.

Lastly, design (walking) speed, start-up delay and headway should reflect the characteristics of local users in designing signalized crosswalks in order not to increase delay for vehicles by allowing excessive green and flashing red for pedestrians. All these issues identified above should be further researched and addressed by specialized studies.

Chapter 5

OPERATIONAL ANALYSIS: PEDESTRIAN AND TURNING-VEHICLE INTERACTIONS AT SIGNALIZED INTERSECTION CROSSWALKS

5.1. Introduction

It is a common practice for pedestrians to share the right-of-way with turning vehicles. At signalized intersections, right- and/or left-turning vehicles are often allowed to perform their maneuvers during the pedestrian "WALK" signal indication. This situation creates conflicts between pedestrians and vehicles that preempt the crosswalk space. Such conflicts introduce delays to pedestrians and turning vehicles, and increase the likelihood for a crash to occur. On the other hand, the reduction of pedestrian-vehicle conflicts through the application of proper traffic-control measures (e.g., early or late release of pedestrians) is expected to decrease the overall operational efficiency of the signalized intersection. Thus, a trade-off exists between providing pedestrian safety and crossing convenience, and generating operational efficiency.

The existing pedestrian signal phasing at the signalized intersections with left-turns allowed from cross streets onto Grand River Avenue is called "combined pedestrian-vehicle interval" and is the most common form of pedestrian signal phasing used in practice. It is defined in the *Manual of Uniform Traffic Control Devices* as "a signal phasing wherein pedestrians may use certain crosswalks and vehicles are permitted to turn across these crosswalks."

Chapter 5 examines the interactions between turning vehicles and pedestrians crossing at the signalized intersections on Grand River Avenue. The motive for this type of analysis was given by numerous comments from pedestrian users surveyed in a study by Sisiopiku and Akin (1999:1). Sisiopiku and Akin reported that pedestrian users preferred to cross at non-designated crosswalks on Grand River Avenue in order to avoid conflicts with turning vehicles during pedestrian green interval. Moreover, turning movements at intersections are much more hazardous than through movements in terms of crashes between vehicles and pedestrians. Pedestrian crosswalks that are independent from turning-vehicle pedestrian conflicts show a lower pedestrian accident experience (Fruin, 1973). Thus, conflicts between turning vehicles and pedestrians crossing at the signalized crosswalks are to be studied in this part of the study.

The results from this analysis are used in order to classify intersections with respect to the risk they impose to pedestrian movements. Furthermore, a correlation between pedestrian-vehicle conflicts and/or crashes and geometry and signal timing/phasing can be examined to further assess safety at a crossing location and determine the need for geometric and/or signal timing/phasing improvements. Such analysis is beyond the scope of the subject research and is recommended for further study in the future.

5.2. Methodology

First, the definition of potential conflict and potential conflict area are offered. Then, results from statistical modeling of potential pedestrian conflicts with turning vehicles are presented.

5.2.1. Definition of Potential Conflict and Potential Conflict Area (PCA)

A potential turning vehicle-pedestrian conflict is defined as a situation in which the paths of a turning vehicle and a pedestrian cross and both pedestrian and vehicle are present simultaneously within the conflict area. The conflict area is defined in Figures 5.1 and 5.2 for right- and left-turning vehicle-pedestrian conflicts, respectively.

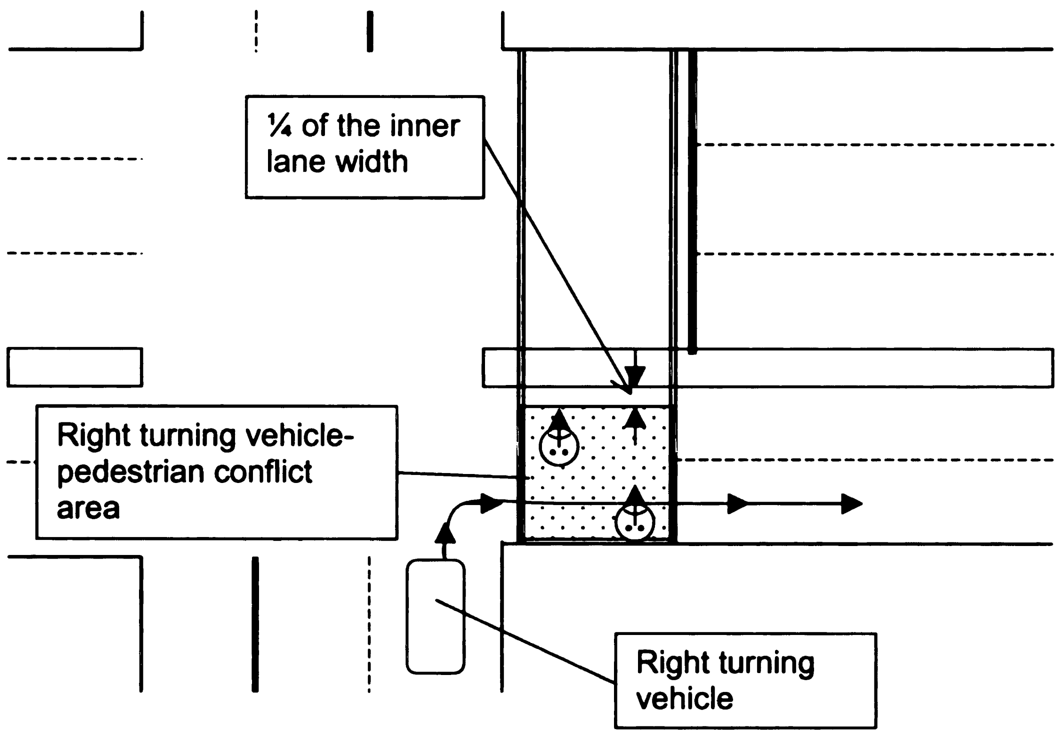


Figure 5.1. Right-turn vehicle-pedestrian conflict area on a crosswalk

Field data were collected at the four signalized intersection crosswalk locations along Grand River Avenue. First, potential conflicts, observed as a result of turning vehicle-pedestrian interactions, were counted. Then, regression analysis was performed to develop relationships between measured conflicts, and pedestrian and vehicle volumes.

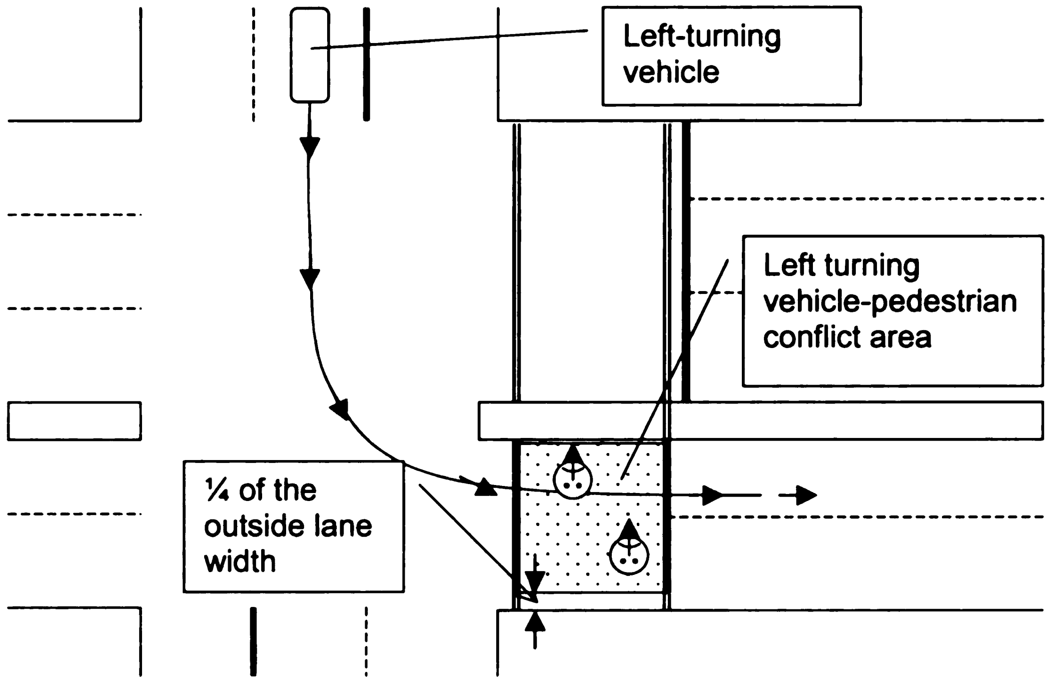


Figure 5.2. Left-turn vehicle-pedestrian conflict area on a crosswalk

5.2.2. Modeling of Potential Conflicts with Turning Vehicles

Conflict analysis technique and the relationship between conflicts and accidents were studied by several researchers during the last 20 years. Cynecki (1980), Glauz et al. (1985), Garder (1989), Davis et al. (1989) and several others defined the calculation of a conflict as the product of two counteract movements, for example, turning vehicles and pedestrians walking in a crosswalk during pedestrian green interval. Modeling experiments with alternative formulations toward a model that is reasonable and intuitively correct led to the same form of equation found in the literature: $Y = a\ (X_1\ .\ X_2)$. The number of potential pedestrian conflicts with turning vehicles is the dependent variable, Y; X_1 is the volume of turning vehicles; X_2 is the volume of pedestrians in the crosswalk; and a is a regression parameter. Garder (1989) used a similar formula to calculate pedestrian accidents with motor vehicles: $C = a\ (P.V)^{1/2}.10^{-2}$, where C is accidents per year, a is a constant and varied with the type of traffic control at intersections, and P and V are pedestrian and vehicle flows respectively. Similarly pedestrian conflicts with turning vehicles are the product of turning vehicle flow and pedestrian flow. Thus the following model formulation is proposed and used for the determination of turning vehicle-pedestrian conflicts:

$$TVPC = A.(TVV.PV) \quad \text{Eq5.1}$$

where

TVPC = number of turning vehicle-pedestrian conflicts (conflicts/hr),

TVV = turning vehicle volume at signalized intersections (veh/hr),

PV = pedestrian volume in signalized intersection crosswalks (ped/hr), and

A = regression coefficient.

5.3. Data Collection

Potential turning vehicle-pedestrian conflicts were counted over 30-min periods and then converted into the number of potential conflicts per hour for each signalized intersection crosswalk within the study site. Note that at the signalized intersection of M.A.C. Avenue, no pedestrian conflicts with turning vehicles exist because the crosswalk is located at the east-side of the intersection and no left-turn movement is allowed from M.A.C. onto Grand River Avenue. The Abbott Street intersection crosswalk poses both left- and right-turn vehicle conflicts to pedestrians. The crosswalk at Division Street has only left-turn vehicle-pedestrian conflicts existed since the intersection does not have a south leg. The Collingwood-west intersection crosswalk poses both left- and right-turn vehicle-pedestrian conflicts to pedestrians. At the Collingwood-east intersection crosswalk, left-turn vehicles are not allowed and, thus, only right-turn vehicle-pedestrian conflicts were counted.

Table 5.1 summarizes potential right-turn vehicle-pedestrian conflicts observed at the signalized intersection crosswalks. As Table 5.1 indicates, the signalized intersection crosswalk at Abbott Street has the highest average potential right-turn vehicle-pedestrian conflicts per hour (41 potential conflicts/hr) followed by the crosswalk at the east-side of Collingwood intersection (24 potential conflicts/hr).

Table 5.1. Potential right-turn vehicle pedestrian conflicts (RTVPC) in study intersection crosswalks

Crosswalks	Average right-turning vehicle volume (veh/hour)	Average pedestrian volume (ped/hour)	Average potential right-turn conflicts (conflicts/ hour)
Abbott St	40	154	41
Division St	N/A	323	N/A
Collingwood-W	20	50	5
Collingwood-E	151	56	24

N/A: not applicable

Table 5.2 summarizes potential left-turn vehicle-pedestrian conflicts observed at the signalized intersection crosswalks. As shown, the crosswalk at Division Street has the highest average left-turn potential pedestrian-vehicle conflict rate. Note that this intersection serves also the highest left-turning vehicle and pedestrian crossing volumes among all the signalized intersections studied.

Table 5.2. Potential left-turn vehicle pedestrian conflicts (LTVPC) in study intersection crosswalks

Crosswalks	Average left-turning vehicle volume (veh/hour)	Average pedestrian volume (ped/hour)	Average potential left-turn conflicts (ped/ hour)
Abbott St	54	154	11
Division St	154	323	159
Collingwood-W	104	50	42
Collingwood-E	N/A	56	N/A

N/A: not applicable

Also, according to Table 5.2, a very low left-turn conflict rate was observed at the Abbott Street crosswalk. This can be explained by the low left-turn vehicle volume (54 vph) as well as the fact that left turning vehicles are given a permissive phase during the movement of northbound traffic. Due to the lack of exclusive right of way, left-turning vehicles conflict first with northbound through traffic and then with pedestrian traffic at the crosswalk. As a result, many pedestrians can safely clear the conflict area while left-turning vehicles wait for northbound traffic to clear, prior to entering the conflict area at the crosswalk. The same situation occurs at the Collingwood-west intersection crosswalk. However, at this crosswalk, left-turn traffic from Collingwood Street onto Grand River Ave is not opposed by a heavy southbound through movement.

5.4. Analysis and Results

The collection of turning vehicle-pedestrian conflict data in the field was a tedious and time-consuming process. The following paragraphs present the results from an effort to estimate potential conflicts based on turning vehicle and pedestrian volumes. Regression analysis techniques were employed to model the relationship between potential turning vehicle-pedestrian conflicts and turning vehicle and pedestrian volumes. The results are presented next by turning movement type (i.e., right- or left- turning movement).

5.4.1. Right-turning Vehicle-Pedestrian Conflicts

Figure 5.3 presents a plot of potential right-turn vehicle-pedestrian conflicts (per hour) versus right-turn vehicle volumes. Figure 5.4 depicts the existence of a correlation between right-turn vehicle-pedestrian conflicts and pedestrian volume. Observation of the two plots shows a potential correlation between right-turn vehicle-pedestrian conflicts and both vehicle and pedestrian volumes. This correlation was modeled in Equation 5.2.

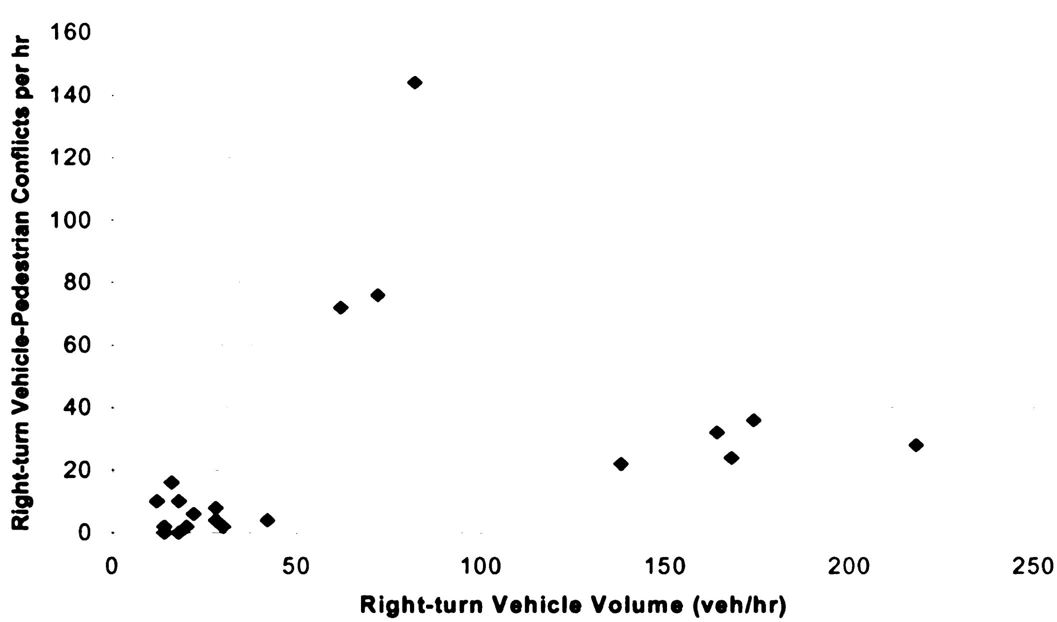


Figure 5.3. Relationship between right-turn vehicle-pedestrian conflicts and right-turn vehicle volume at the signalized intersection crosswalks

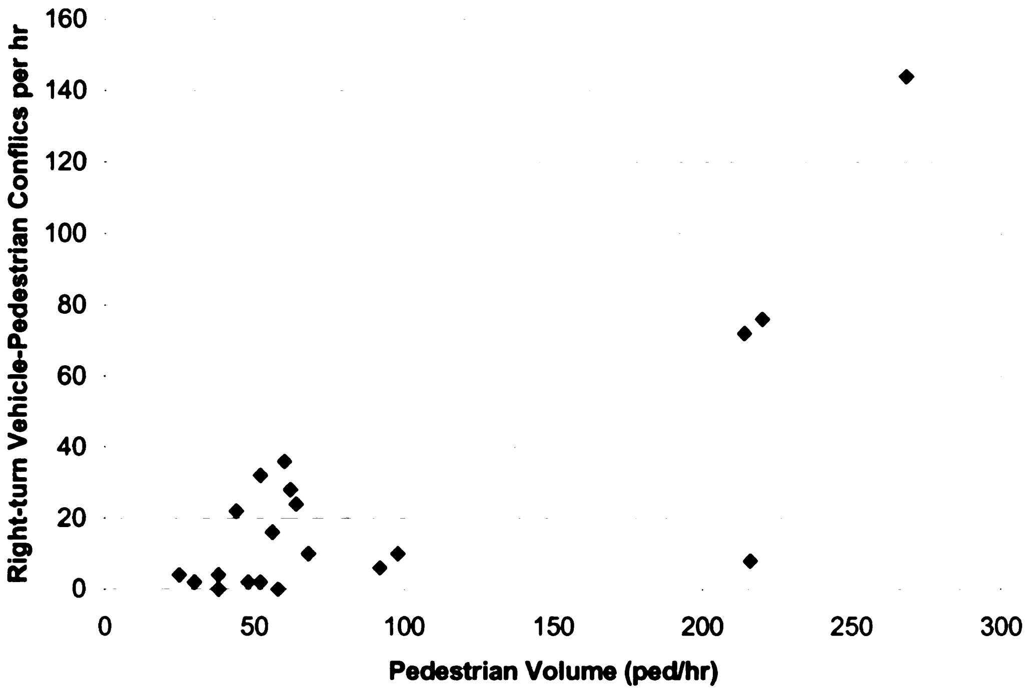


Figure 5.4. Relationship between right-turn vehicle-pedestrian conflicts and pedestrian volume at the signalized intersection crosswalks

Regression analysis yielded an A value equal to 4.641 $*10^{-3}$ as shown in the following model:

$$RTVPC = 4.641.10^{-3}(RTVV.PV)\ldots\ldots Eq5.2$$

where

RTVPC = number of right turning vehicle-pedestrian conflicts (conflicts/hr),

RTVV = right-turning vehicle volume (veh/hr), and

PV = pedestrian volume (ped/hr).

The regression analysis results are presented in detail in Table 5.3. The goodness of fit of the model, R^2 value, is 0.872. Figure 5.5 shows the plot of measured data and the model estimates based on Equation 5.2. Overall the model appears to predict potential right-turn vehicle-pedestrian conflicts reasonably well when right turn vehicle and pedestrian volumes are known.

Table 5.3. Linear regression analysis results for the RTVPC model

Model		Sum of Squares	Df	Mean Square	F	Sig
1	Regression	31882.590	1	31882.590	136.326	0.000
	Residual	4677.410	20	233.871		
	Total	36560.000	21			

Unstandardized Coefficients		Standardized Coefficients	t	Significance level	95% CI for coefficients	
A	Std. Error	A			Upper	Lower
4.641E-03	0.000	0.934	11.676	0.000	0.004	0.005

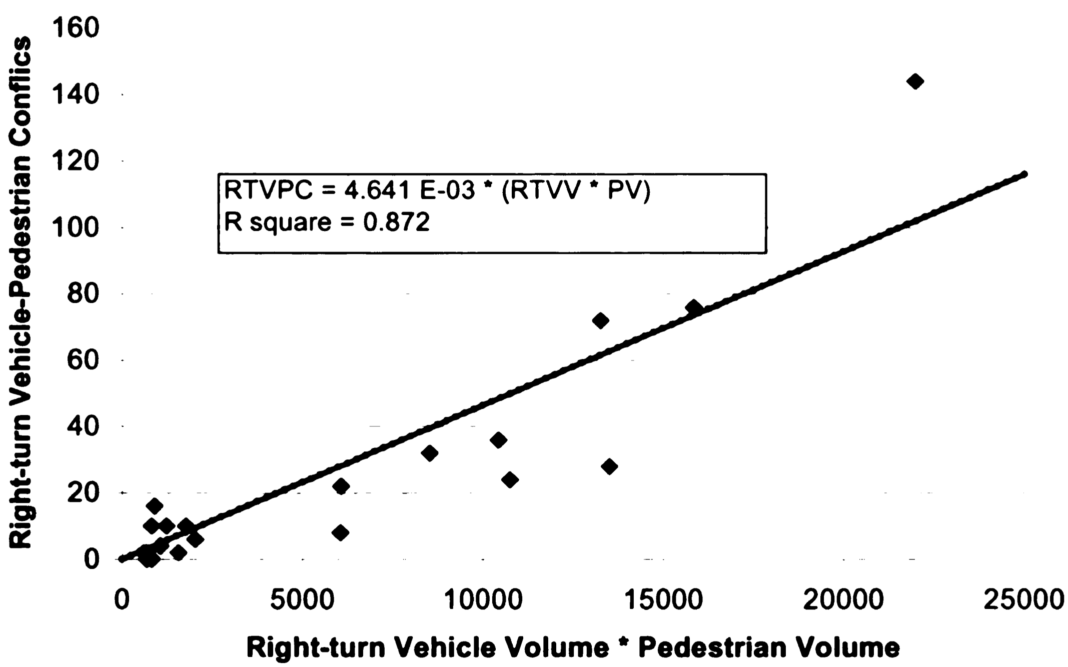


Figure 5.5. Relationship between right-turn vehicle-pedestrian conflicts, and right-turn vehicle and pedestrian volumes

5.4.2. Left-turning Vehicle-Pedestrian Conflicts

Figure 5.6 presents a plot of potential left-turn vehicle-pedestrian conflicts (per hour) versus left-turn vehicle volume. Figure 5.7 shows the correlation between left-turn vehicle-pedestrian potential conflicts and pedestrian volume. Again, observation of the two plots shows a possible correlation between left-turn vehicle-pedestrian conflicts and left-turning vehicle and pedestrian volumes.

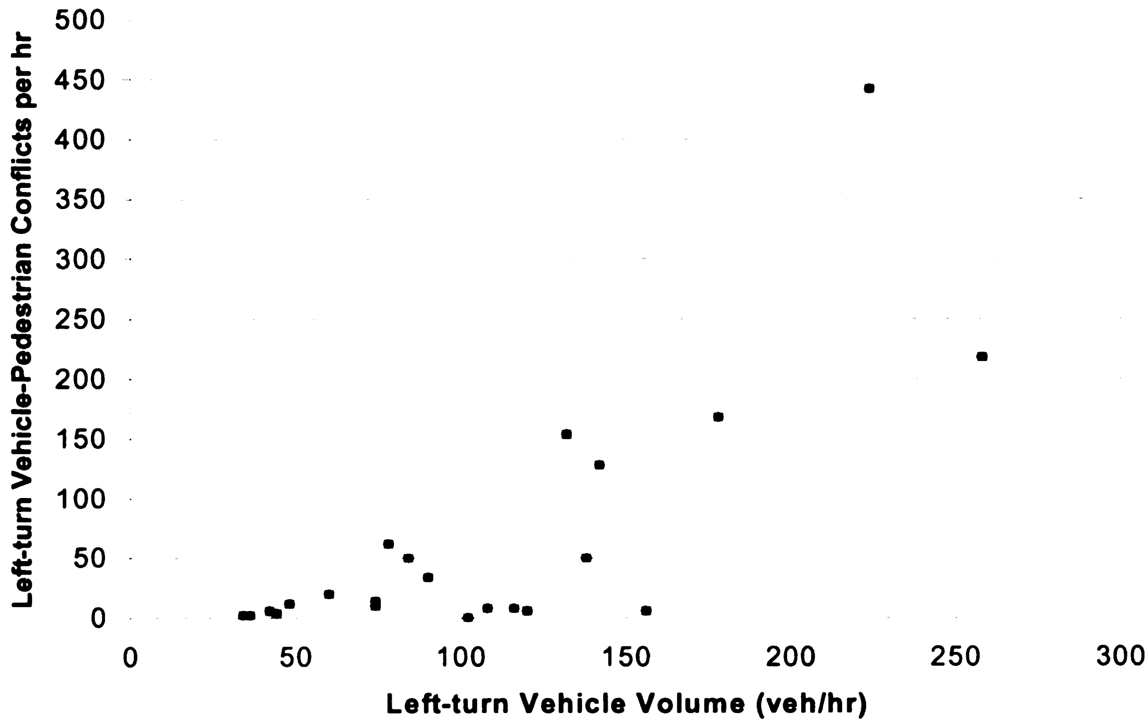


Figure 5.6. Relationship between left-turn vehicle-pedestrian conflicts and left-turn vehicle volume at the signalized intersection crosswalks

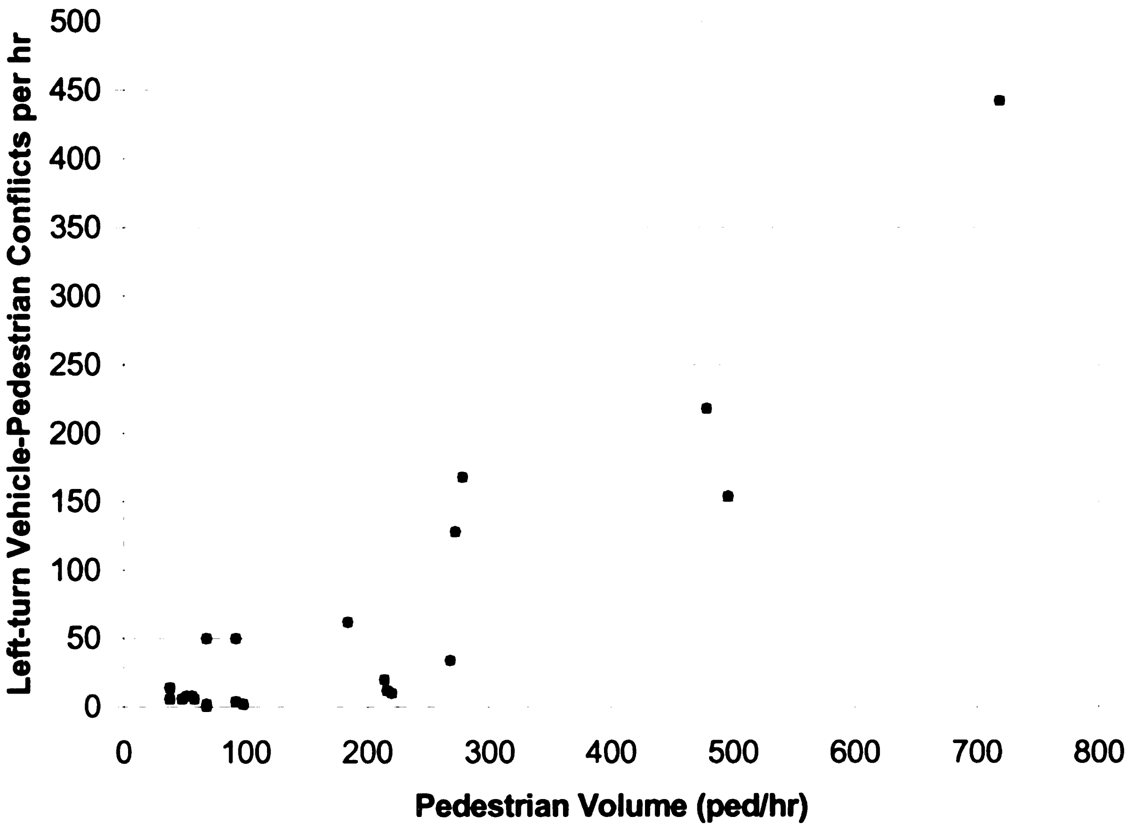


Figure 5.7. Relationship between left-turn vehicle-pedestrian conflicts and pedestrian volume at the signalized intersection crosswalks

The linear regression analysis yielded the following model with the R^2 value of 0.945:

$$LTVPC = 2.444.10^{-3}(LTVV.PV) \qquad Eq5.3$$

where

LTVPC = number of left-turning vehicle-pedestrian conflicts (conflicts/hr),

LTVV = left-turning vehicle volume (veh/hr), and

PV = pedestrians volume (ped/hr).

Summary results from the linear regression analysis are presented in Table 5.4.

Table 5.4. Linear regression analysis results for the LTVPC model

Model		Sum of Squares	df	Mean Square	F	Sig+
1	Regression	304677.028	1	304677.028	362.814	0.000
	Residual	17634.972	21	839.761		
	Total	322312.000	22			

Unstandardized Coefficients		Standardized Coefficients	t	Sig	95% CI* for coefficients	
B	Std. Error	B			Upper	Lower
2.444E-03	0.000	0.972	19.048	0.000	0.002	0.003

*CI: confidence interval, +Sig: significance

Figure 5.8 shows the plot of the data and the model estimates resulting from the application of Equation 5.3. Both the high R^2 (0.945) value obtained and the very good fit of the model to the data (as shown in Figure 5.8) indicate that Equation 5.3 can predict potential left-turning vehicle and pedestrian conflicts with reasonable accuracy when left-turning vehicle and pedestrian volumes are known.

In Table 5.5, the study intersections are ordered based on the total potential turning vehicle-pedestrian conflict rates per hour per thousand vehicles and pedestrians as formulated in Equation 5.4. Such classification assists in identifying intersections with a greater risk for pedestrian-turning vehicle collisions and setting priorities for potential improvements.

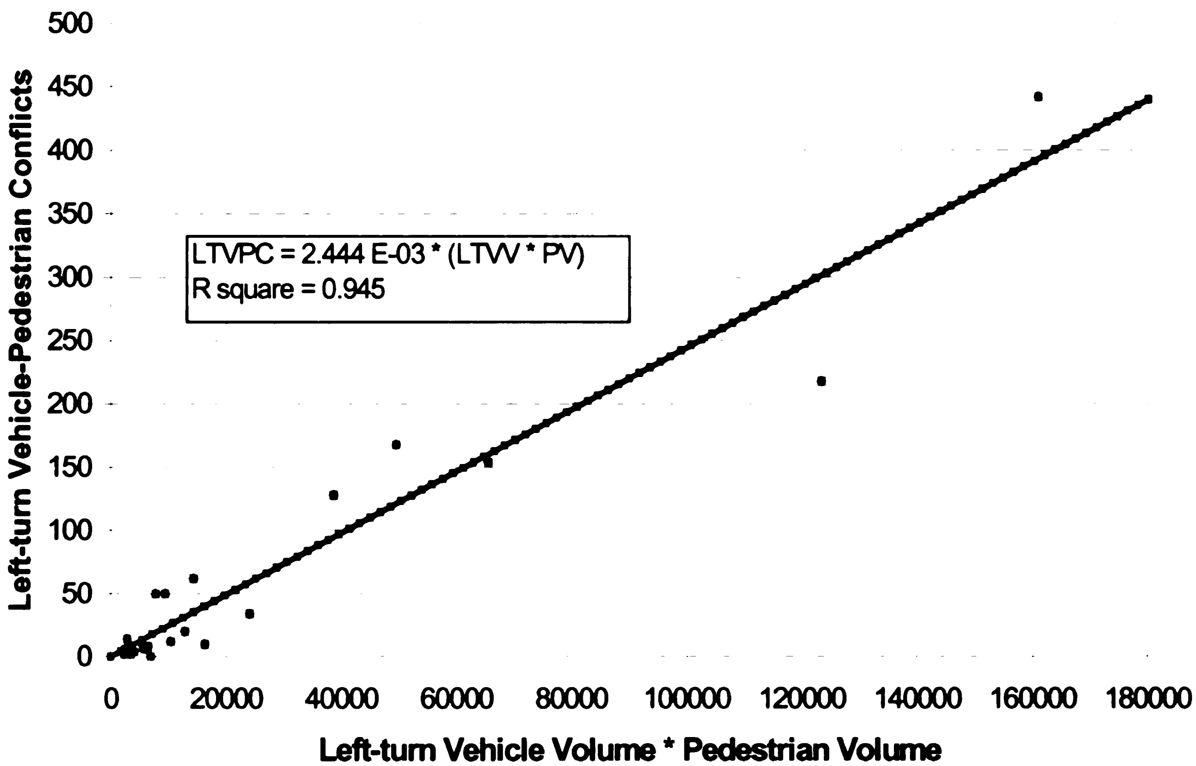


Figure 5.8. Relationship between left-turn vehicle-pedestrian conflicts, and left-turn vehicle and pedestrian volumes

$$PCR = \frac{TPC.10^3}{TVV.PV} \qquad Eq.5.4$$

where

PCR: Potential conflict rate (number of potential conflicts per hour per thousand vehicles and pedestrians),

TPC: Total potential conflicts. The sum of both types of conflicts per hour (if applicable) on a crosswalk,

TVV: Total vehicular volume. The sum of left- and right-turning vehicular volumes (veh/hr), and

PV: Pedestrian volume on a crosswalk per hour.

Table 5.5. Classification of the signalized intersection crosswalks based on total potential turning vehicle-pedestrian conflicts

Intersection	TPC	TVV	PV	PCR	Priority for consideration for action
Collingwood-W	47	124	50	7.58	1
Abbott	52	94	154	3.59	2
Division	159	154	323	3.20	3
Collingwood-E	24	151	56	2.84	4

According to Table 5.5, the west crosswalk at Collingwood Street is clearly the one with the greatest potential for turning vehicle-pedestrian collisions on the basis of potential pedestrian conflicts with turning vehicles. To improve the situation, early or late release or exclusive pedestrian signal timing can be used, to replace the concurrent signal timing currently in effect. Early or late release pedestrian signal timing is expected to assist in reducing the number of conflicts between pedestrians and turning traffic with expected benefits with respect to pedestrian safety and pedestrian crossing compliance. However, due to potential implications on operational efficiency, a detailed study is recommended to take place prior to implementation of an alternative signal-timing plan.

5.5. Summary and Conclusions

In this chapter, pedestrian-turning vehicle interactions at the signalized intersection crosswalks were studied in detail. First, potential right- and left-turn vehicle-pedestrian conflicts at the signalized intersection crosswalks were defined and measured at qualifying locations within the study area. Potential conflict estimation models were developed and discussed. The proposed models can be used to estimate potential right- and left- turning vehicle-pedestrian conflicts when turning vehicle and pedestrian volumes are available. Determining the conflicts provide traffic engineers information about potential hazards at intersections. If the number of the conflicts is significantly higher compared to similar locations, then safety precautions need to be taken in order to reduce the number of conflicts by implementing early/late release of vehicles/pedestrians.

The following conclusions were reached from the analysis described above:

- The estimation of potential right- and left-turning vehicle-pedestrian conflicts is possible through the application of regression models developed in this study and presented in Equations 5.2 and 5.3.
- The models indicated that the product of pedestrian and turning vehicle volumes is highly correlated with the conflicts with pedestrians and turning vehicles.
- Literature review indicated that early or late release pedestrian signal phasing could contribute to the reduction in turning vehicle-pedestrian conflicts and increase in pedestrian safety and crossing convenience.

5.6. Recommendations for Future Research

The following recommendations were made for future research:

- Although the models proposed in this chapter give very reasonable results, additional testing of the models is recommended to confirm their validity and applicability in different settings.
- The models proposed for the estimation of potential turning-vehicle-pedestrian conflicts are applicable to combined pedestrian-vehicle phasing only. Validation of the models is needed for other pedestrian signal phasing schemes (e.g., early or late release).
- The relationship between pedestrian crashes and pedestrian-vehicle conflicts was not studied. A future study should investigate this relationship.

Chapter 6

ANALYSIS OF PEDESTRIANS' PERCEPTIONS AND PREFERENCES

6.1. Introduction

The main focus of this part of the study is to analyze users' perceptions and preferences toward various pedestrian treatments, including signalized and unsignalized intersection crosswalks, midblock crosswalks, pedestrian signs and signals, physical barriers and more. Crossing preferences and habits of pedestrians were also studied to determine current crossing practices and explain the reasoning behind their choices.

Users' perceptions and preferences should be taken into account when the operation of pedestrian facilities is evaluated. Pedestrians should be offered the opportunity to identify treatments that create safe and desirable crossing options and environment that increase their likelihood to properly use pedestrian designated facilities. The latter is crucial toward the improvement of pedestrian safety. When pedestrians use sidewalks and properly cross at designated locations, the separation of pedestrians and vehicles increases and pedestrian-vehicle conflicts are minimized.

6.2. Methodology

Pedestrian perception and preference data were collected through a pedestrian survey electronically distributed to potential users of the study site.

6.2.1. Survey Design

Three important steps were considered in order to conduct the survey of users of the study site:

a. selection of a target population,

b. selection of a medium for easy distribution of the survey, and

c. development of a survey instrument.

The Michigan State University (MSU) community was selected as the target population for this study because of familiarity with the study site and a high likelihood of using the facility as pedestrians, motorists, or both. The reason that members of the MSU community were selected as the target population is that a considerable number of students as well as some faculty and staff live in the proximity of Grand River Avenue, in downtown East Lansing. Also, the facility is used by students and personnel who study and/or work at MSU for shopping, entertainment, or catering purposes.

For easy distribution of the survey, electronic media (e-mail addresses) were used to send a copy of the survey to randomly selected receivers. The development of the survey instrument met the following criteria:

- statement of study purpose and importance of participation;
- clear definition of questions;
- reasonable length;
- lack of personal or potentially offensive questions;
- appropriate format for electronic distribution; and
- appropriate format for easy data coding.

The questions included in the questionnaire covered the following areas of interest:

a. users' profile (age group, gender, and frequency of use of the facility),
b. users' crossing patterns (crossing location, conditions, compliance),
c. factors that affect pedestrian crossing choices (presence of certain types of control, user priorities), and
d. users' perceptions with respect to right-of-way and safety.

The survey form included a total of eight questions with several of them soliciting more than one answer. It required approximately 2-3 minutes to complete. The full survey is shown in Figure 6.1. The questionnaire was pre-tested in order to identify any unclear questions with members of a department that is located next to the study site. The selection of the pre-test group was taken under consideration for the proximity of their work place to the study site as well as the availability of e-mailing the survey to the whole department at one time.

6.3. Data Collection and Reduction

First, on-site surveys were conducted by survey staff (graduate students in transportation program at the Department of Civil and Environmental Engineering of MSU) who was instructed to randomly approach pedestrians in the study site. Fifty-two pedestrians were approached and asked for their assistance in completing the survey. Twenty-two of those agreed to participate in it. Although

Figure 6.1. Grand River Avenue Pedestrian Survey

1. How often do you cross on Grand River Ave between Abbott and Bogue Streets on foot? (Please mark your answers by X).
____ 1. Daily ____ 2. Occasionally (a couple days a week) ____ 3. Almost never

2. Where do you typically cross on Grand River Ave?
____ 1- on designated signalized crosswalks
____ 2- on designated midblock and unsignalized crosswalks
____ 3- at any convenient location

3. When do you typically cross on Grand River Ave?
____ 1- only when pedestrian traffic light is green
____ 2- when traffic clears completely
____ 3- whenever a gap occurs in vehicular traffic

4. How often do you cross at a non-designated crossing location?
____ 1- never ____ 2- rarely ____ 3- sometimes ____ 4- often ____ 5- almost always

5. If you choose to cross at a non-designated crossing location, what is the main reason?
____ 1- convenience ____ 2- to save time ____ 3- traffic is light, there is no risk

6. In your opinion, when should vehicles yield to pedestrians?
____ 1- always ____ 2- at designated crosswalks ____ 3- never, vehicles should have priority

7. Are the following statements true for Grand River Ave.?
1 2
Y__ N__ a- motorists typically yield to pedestrians at designated crosswalks
Y__ N__ b- left-turning vehicles typically yield to pedestrians during pedestrian green
Y__ N__ c- pedestrians typically cross at designated locations
Y__ N__ d- bicycles do not pose a safety risk to pedestrians at designated crosswalks

8. Do the following influence your decision to cross at a certain location?
1 2
Y__ N__ 1- presence of a pedestrian signal
Y__ N__ 2- presence of a midblock crosswalk
Y__ N__ 3- red color brick pavement
Y__ N__ 4- shelter over a midblock crosswalk
Y__ N__ 5- "cross only when traffic clears" sign
Y__ N__ 6- presence of other pedestrians that attempt to cross
Y__ N__ 7- distance to a desired location
Y__ N__ 8- vegetation or barriers on a median

Figure 6.1. Grand River Avenue Pedestrian Survey (continued)

9. How often are you willing to divert from your path in order to cross at a designated crosswalk?
____ 1- always ____ 2- often ____ 3- sometimes____ 4- rarely ____ 5- never

10. What is your age group?
____ 1- less than 21 yrs ____ 2- 21-55 yrs ____ 3-over 55 yrs

11. What is your gender?
____ 1- male _____ 2- female

12. Do you perceive Grand River Ave between Abbott and Bogue St as a safe corridor for pedestrians?
____ 1- Yes ____ 2- No

13. If your answer in Q. 12 is "No," what is the major problem from your point of view?

the rate of participation of the on-site survey was good (42.3%), this data collection approach was found to be time consuming and costly. Thus a decision was made to distribute the survey instrument electronically instead.

The survey was distributed to e-mail recipients selected randomly via the MSU computer network. Selection of 5,000 e-mail addresses was made randomly from the available e-mail addresses (over 90,000) in the computer network. A total of 897 completed questionnaires were returned and reviewed. The return rate was 17.9%. Given that the typical return rate of mail-in surveys reported in the literature is between 5 and 30%, the return rate of the subject survey was deemed acceptable. It should be noted that some of the e-mail addresses in the database are invalid or inactive. For this reason, it is believed that the real return rate would easily exceed 20%.

Returned questionnaires were first screened to assess their completeness and ensure their uniqueness. During this process, duplicate copies and forms with several unanswered questions were eliminated. Eligible questionnaires were assigned a serial number. This allowed for future tracking of selected surveys to check for coding errors. After eliminating duplicate and incomplete survey forms a total of 855 questionnaires remained plus 22 on-site surveys. A decision was made to analyze responses from daily and occasional users, and non-users separately. It is believed that non-users completed the survey based on their previous experiences, not the experiences from the study site. So, combining all responses together could introduce some bias to the results. A total of 711 questionnaires from daily and occasional users were used in the analysis. The sample size was deemed adequate to provide a fairly accurate picture of the users' crossing habits, observations and perceptions toward the pedestrian facilities in the test site. The next section summarizes results from the analysis of survey data.

6.4. Analysis and Results

The Statistical Package for the Social Sciences (SPSS) program was used to create a file containing the responses from each questionnaire. This package has the capability to perform statistical analysis as well as produce graphs and data summaries. Each survey was coded to a single raw and a serial number was assigned in order to track it later, if necessary. There were 22 fields per questionnaire and 45 sec to 1 min per survey were required to complete a typical data entry.

Out of the 877 pedestrians studied, 255 (29.1%) pedestrians used the study site "daily," 456 pedestrians, or 52.0% was classified as "occasional users (who use the study site for a couple days a week)," and the rest (166 pedestrians, or 18.9%) were non-users who stated that they almost never used the study site.

The percentage of respondents 21 years or younger was 32.7%, between 22 and 55 years of age was 61.6%, and the remaining 5.7% was over 55 years of age. The fairly normal age distribution is an indication of a representative and properly diverse sample population.

6.4.1. Daily and Occasional Users

Out of the 711 daily and occasional pedestrian users studied, 255 (36%) pedestrians used the study site daily and the rest (456 pedestrians, or 64%) were occasional users.

6.4.1.1. Users' Crossing Patterns

The location at which pedestrians select to cross a road, the conditions under which they decide to cross and their compliance with pedestrian traffic control are important factors both from safety and operation perspectives.

As Figure 6.2 shows, the majority of pedestrians surveyed (59%) said that they typically cross at designated locations (24% at signalized crosswalks, 31% at unsignalized and midblock crosswalks, and 4% at crosswalks of any type). The remaining 41% replied that they typically cross at any convenient location.

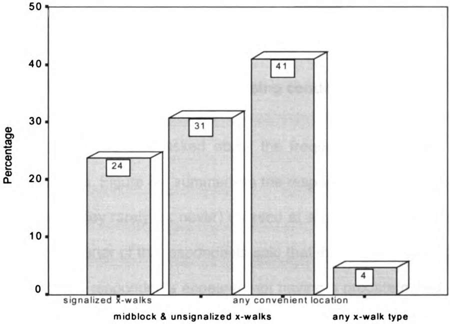


Figure 6.2. Typical pedestrian crossing locations

Figure 6.3 depicts typical crossing conditions for respondents. 61 percent of the respondents admitted to cross when they perceive that an acceptable gap in vehicle traffic exists. On the other hand, 35% said they cross only when all traffic has cleared completely and a mere 4% was willing to wait for a green pedestrian light indication in order to cross.

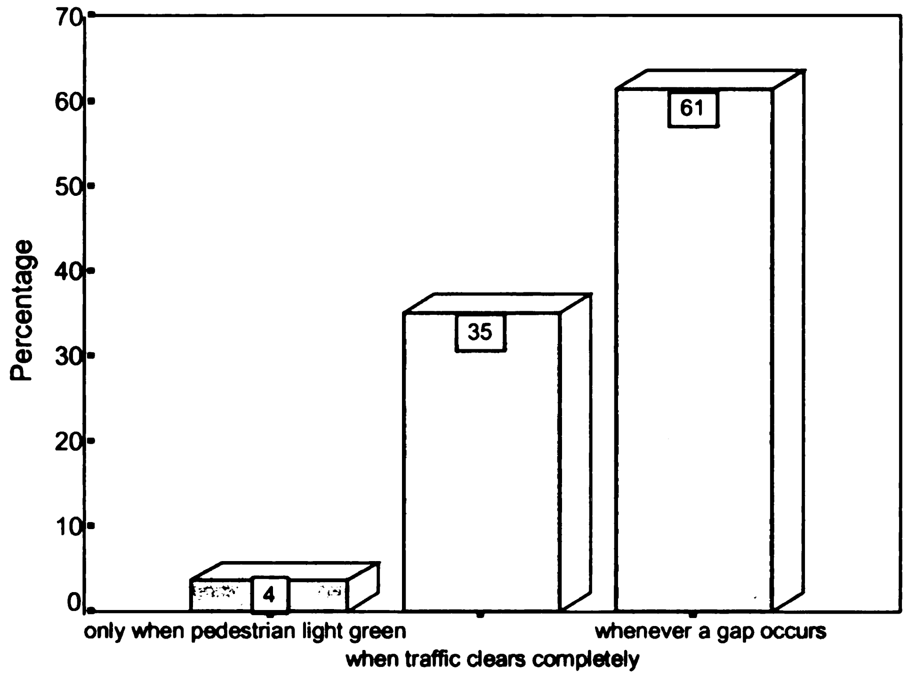


Figure 6.3. Typical pedestrian crossing conditions

Pedestrians were also asked about the frequency of crossing at non-designated locations. Figure 6.4 summarizes the responses obtained. 29% of the users replied that they rarely (or never) crossed at a non-designated crosswalk. Approximately a quarter of the respondents said that they often or almost always jaywalk. 46% of the respondents appeared not having a predetermined crossing preference on the use of designated facilities in order to cross. These results are in reasonable agreement with the responses regarding preferred crossing location presented above and the users' willingness to divert from their path in order to cross at a designated location. 38% of users replied that were willing to divert, 20% refused to do so, and 42% said that they would sometimes divert from their path in order to use a crosswalk.

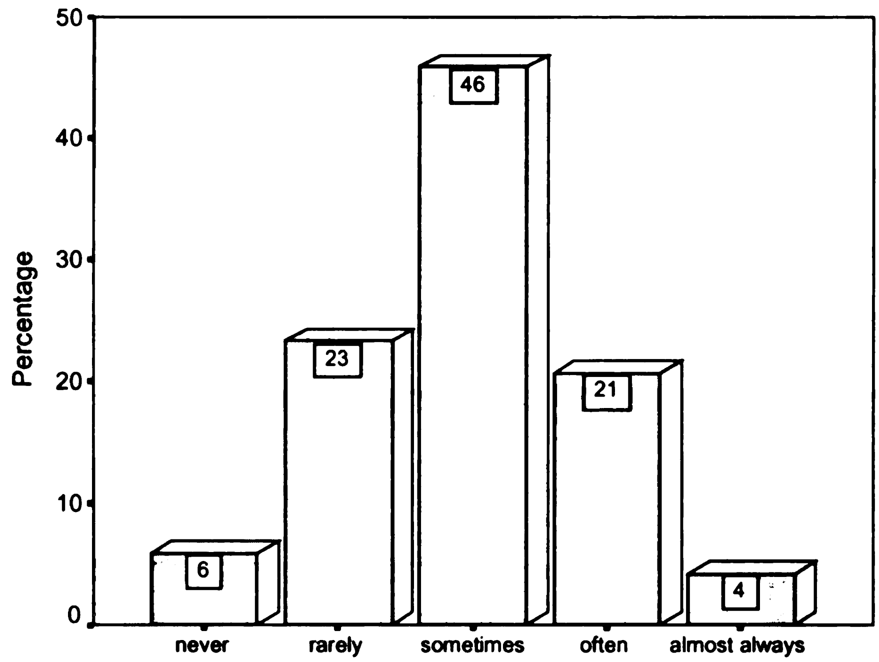


Figure 6.4. Frequency of crossing at a non-designated crossing location

It is also interesting to note that occasional users appear to be more conservative in their crossing choices. For example, only 18% of occasional users admit to cross frequently at non-designated locations compared to 34% of daily users. This leads to the conclusion that when pedestrian facilities are designed for primary use by pedestrian commuters more intensive efforts should be made in order to discourage pedestrians from crossing at non-designated location. Such behavior may pose a risk for the personal safety of pedestrians and create undesirable disruptions of traffic flow.

6.4.1.2. Assessment of Factors Affecting Pedestrian Crossing Choices

Pedestrians were asked to state the main reason based on which they make a decision to cross at a non-designated crosswalk location. The answers to this question were indented to assess the users' priorities. Convenience is the number one priority sited by users (42%) while time savings was of major importance to 27% of the respondents. Interestingly enough, 30% responded that they do not perceive any major risk crossing the facility at any convenient location since traffic is light enough to allow for safe crossing. These results are summarized in Figure 6.5.

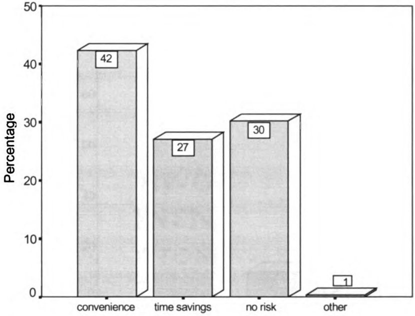


Figure 6.5. Main reasons to cross at a non-designated crossing location

The effect of the presence of certain types of control on the decision of pedestrians to use pedestrian facilities properly (or not) is of major importance to traffic engineers in designing such facilities. Thus, the subjects were asked a series of yes-or-no questions about treatments that influence their decision to cross at a certain location. Such treatments included existence of pedestrian signal, presence of midblock crosswalk, red color brick pavement or shelter on the median at midblock crosswalk locations, vegetation or barriers on the median, and the location of the crosswalk relative to the desired destination.

The results indicate that the distance to a desired destination is a major crossing-location choice determinant for a vast majority of pedestrians surveyed (90% of total), as is the presence of a midblock crosswalk and/or a pedestrian traffic light for 83% and 74% of survey respondents respectively (Figures 6.6 to 6.8). Vegetation and barriers influenced the decision to cross of a relatively

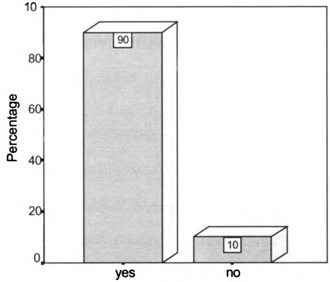


Figure 6.6 Distance to a desired location influences pedestrians' decision to cross at a certain location

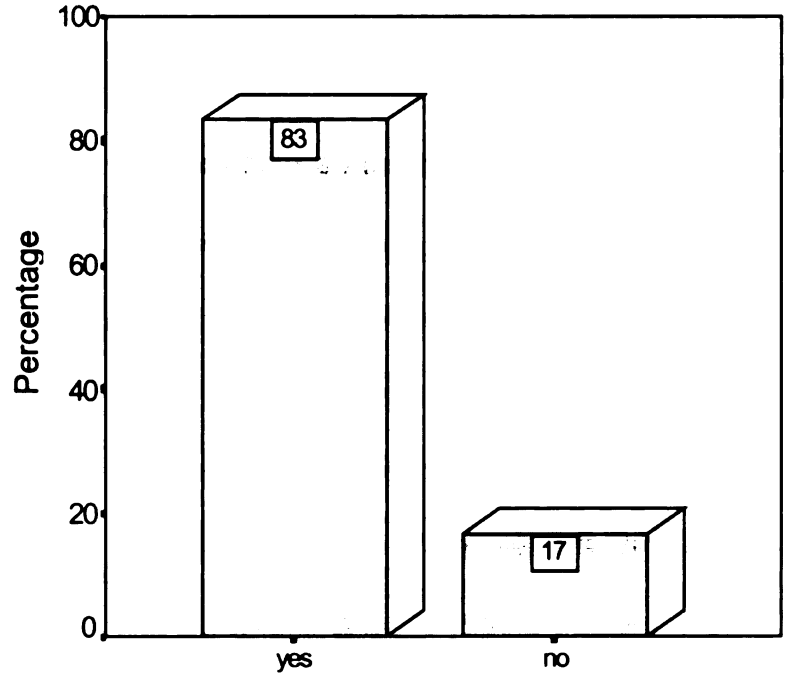


Figure 6.7. Presence of a midblock crosswalk influences pedestrians' decision to cross at a certain location

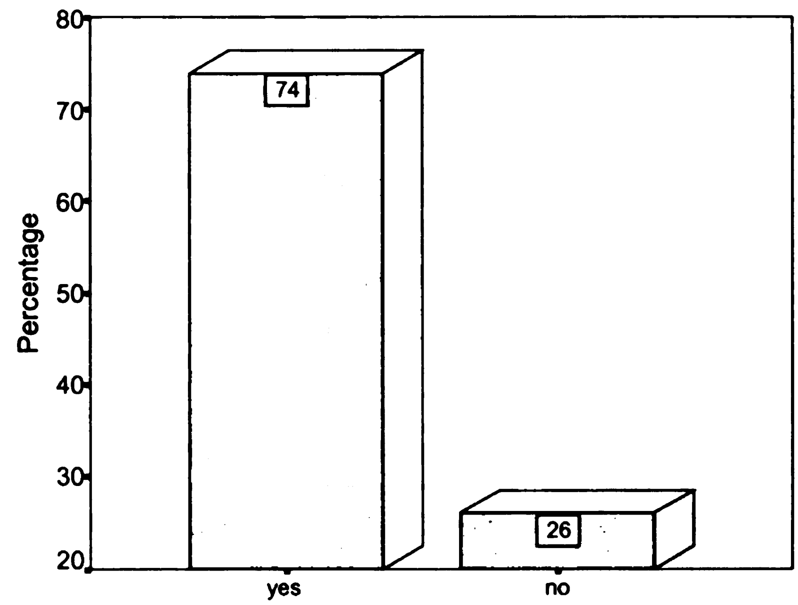


Figure 6.8. Existence of a pedestrian signal influences pedestrians' decision to cross at a certain location

significant number of pedestrians surveyed (65%). On the other hand, respondents had mixed opinions about shelters and red brick paving. Only 35% said that shelters positioned in the median influenced their decision to cross at this location and 58% favored colored paving. Overall, these types of treatments may help pedestrians locate a crosswalk but appear not to have an important influence on their decision to cross at a certain location.

Furthermore, statistical tests were performed to study if there is any significant difference between responses obtained from responders in different age groups or gender classification. The results from the analysis are summarized in Tables 6.1 and 6.2. In summary, it was found that differences in the responses obtained by age classification and gender are not statistically significant at the confidence level of 95%. Thus the use of aggregate results appears appropriate. The only exception occurred to the question about the effect of the distance to the desired location on the decision of an individual to cross. 92% and 90% of respondents in the age group below 21 and between 21 and 55 years of age responded positively, while 74% of elderly gave a positive

Table 6.1. Effect of age on survey responses

Most influential factors	Age Group		
	Chi-square	Significance level	Comment (95% CL)*
Distance to destination	10.780	0.005	0.005<0.05 differences statistically significant
Midblock crosswalk presence	4.550	0.103	0.103>0.05 differences **not** statistically significant
Pedestrian signal presence	1.223	0.542	0.542>0.05 differences **not** statistically significant

*: Confidence Level

Table 6.2. Effect of gender on survey responses

Most influential factors	Gender		
	Chi-square	Significance level	Comment (95% CL)*
Distance to destination	0.892	0.345	0.345>0.05 differences **not** statistically significant
Midblock crosswalk presence	0.433	0.510	0.510>0.05 differences **not** statistically significant
Pedestrian signal presence	1.799	0.180	0.180>0.05 differences **not** statistically significant

*: Confidence Level

response to this question. The analysis indicated that the response of elderly pedestrians to this question was statistically different from the other two study groups at the confidence level of 95% (significance level 0.005<0.05).

6.4.1.3. Users' Perceptions With Respect to Right-of-Way and Safety

A number of questions were asked in order to assess the perceived level of safety and users opinions regarding right-of-way. It was found that 45% of pedestrians using the study site believed that drivers typically yielded to pedestrians in designated locations, especially at midblock crossings when stopped queues could otherwise occupy the crosswalk.

It should be noted that, except from the pavement markings, motorists do not see any positive type of control indicating that pedestrians should be offered priority. Interestingly, when pedestrians surveyed were asked, "when should motorists yield to pedestrians?," the majority (61%) of respondents answered that this should happen only at designated crosswalks. 31% felt that pedestrians should always have priority over motorized traffic, and 7% responded that vehicles should always receive the right-of-way. Pedestrians' replies show that the majority of users understand the purpose of streets with mixed traffic and are willing to compromise in order to help create a fair and safe travel environment for all users.

With respect to turning vehicular traffic, half of the respondents complained that turning vehicles do not respect pedestrians that attempt to cross at signalized intersections during green. This has also been verified by field observations. In most cases, pedestrians and right- or left-turning vehicles share the same green phase with pedestrians. This situation is cited as a reason for pedestrians choosing to cross the road at locations other than signalized intersection crosswalks during green. This is an important finding that demonstrates the important role of proper signal timing settings toward the improvement of safety and efficiency.

Moreover, only 35% of the users said that a pedestrian sign displaying the message “Cross only when traffic clears” made a difference in their decision to cross. Analysis of respondents' comments further indicates that this sign often confused or offended pedestrians that have selected to cross at a designated crosswalk under the impression that they can have the right-of-way.

As pedestrians often compete with bicycles for the same space, the subjects were also asked to provide their input regarding safety issues that may result from this type of interaction. 59% of the users were not concerned with the interaction between pedestrians and bicycles and did not perceive bicycles as a safety risk factor to pedestrians that cross at designated locations. Finally, over two thirds of the respondents (68%) agreed that the study site is a safe corridor for pedestrians to use.

6.4.2. Non-Users

Responses of the non-users are summarized in Table 6.3 along with the responses of the daily and occasional users to the same questions in order to facilitate comparisons.

Table 6.3. Summary of the responses of survey users

Questions of the survey applied to non-users		Daily and occasional users	Non-users
1. Frequency of crossing at a non-designated crossing area	Never – rarely	29.6%	35.2%
	Sometimes	45.6%	42.1%
	Often – almost always	24.8%	12.8%
2. Main reason to cross at a non-designated crossing area	Convenience	41.9%	47.0%
	To save time	27.4%	20.1%
	Light traffic; no risk	30.3%	32.2%
	Other	0.4%	0.7%
3. How frequently do you divert your path to cross at a designated crosswalk?	Never –rarely	20.1%	12.8%
	Sometimes	42.1%	45.7%
	Often – almost always	37.8%	41.5%
4. When should vehicles yield to pedestrians?	Always	30.7%	26.2%
	At designated x-walks	62.0%	70.1%
	Never	7.2%	3.7%
5. Does the presence of a pedestrian signal influence your decision to cross at a specific location?	Yes	73.9%	78.4%
	No	26.1%	21.6%
6. Does the presence of a midblock x-walk influence your decision to cross at a specific location?	Yes	83.0%	74.7%
	No	17.0%	25.3%

Table 6.3. Summary of the responses of survey users (continued)

Questions of the survey applied to non-users		Daily and occasional users	Non-users
7. Does the red-color brick pavement influence your decision to cross at a specific location?	Yes	41.3%	27.6%
	No	58.7%	72.4%
8. Does the presence of a shelter over a midblock crosswalk influence your decision to cross at a specific location?	Yes	34.2%	32.5%
	No	65.8%	67.5%
9. Does the "cross only when traffic clears" sign influence your decision to cross at a specific location?	Yes	35.2%	42.5%
	No	64.8%	57.5%
10. Does the presence of other pedestrian attempting to cross influence your decision to cross at a specific location?	Yes	68.2%	58.6%
	No	31.8%	41.4%
11.Does the distance to a specific location influence your decision to cross at a specific location?	Yes	89.7%	87.5%
	No	10.3%	12.5%
12. Does vegetation or barriers on the median influence your decision to cross at a specific location?	Yes	64.7%	66.7%
	No	35.3%	33.3%

Table 6.3 does not indicate any significant differences between the answers of both types of users. Differences in their answers do not allow one to reach to reasonable conclusions in terms of their differences in preferences and perceptions toward the existing facilities on Grand River Avenue.

6.4.3. Similarities Between Pedestrian Movement and Perception Data

Pedestrian movement and perception data are independent from each other although both sets of data are obtained from the same study site. Some similarities were observed between both data sets. In this comparison, exact matching of numbers and figures was not sought. Similarity in trends observed in the field and reported by users increases the confidence on survey results and, helps to make concrete conclusions for the treatments that are of preference to pedestrians and are likely to be respected by them.

The main similarities that were identified in movement and perception data trends are summarized as follows:

1. Midblock crosswalks are the crosswalk types of preference of pedestrians. Pedestrian crossing compliance is the highest at the marked midblock crosswalks among all the crosswalks studied in this research. The movement data revealed that 71.2 percent of pedestrians showed compliance with marked midblock crosswalks. The perception data disclosed that 83 percent of the survey respondents said that the presence of a midblock crosswalk influenced their decision to cross at the specific location.
2. Signalized crosswalks are amongst the most preferable locations to cross a street. Movement data yielded 83.13 percent spatial compliance with signalized intersection crosswalks. Similarly, pedestrian perception data indicated that 74 percent of the

respondents agreed that the presence of a pedestrian signal influenced their decision to cross at the specific location.

3. Respondents of the pedestrian survey reported that the majority of turning vehicles failed to yield to pedestrians at the signalized intersection crosswalks. This observation was confirmed during the observation of turning vehicle-pedestrian conflicts at the signalized crosswalks.
4. Another similarity between two data sets concerns observed and perceived safety. Observed safety is expressed in terms of the spatial pedestrian compliance rate and calculated as the average of spatial pedestrian compliance rates at all types of crosswalks on Grand River Avenue. The average spatial compliance rate in the entire study crosswalk was found to be 74.5 percent. Similarly, perception data revealed that 68 percent of the respondents perceived Grand River Ave between Abbott and Bogue Streets as a safe corridor for pedestrians.

The similarities summarized above strengthen the confidence about the dependability of the survey results. In the following, a summary and conclusions from the pedestrian perceptions and preferences study are presented.

6.5. Summary and Conclusions, and Recommendations for Future Research

In Chapter 6, the procedure used to obtain information on pedestrian users' preferences and perceptions was described, and the results from the survey analysis were discussed. The analysis of survey data provided important insights on attitudes and preferences of pedestrians using the study site. The following conclusions were drawn:

- Properly marked pedestrian facilities encourage users to cross at a certain location. More specifically, the marked midblock crosswalks were found to be very influential pedestrian facilities. This was also supported by actual movement data analysis.
- The signalized intersections with crosswalks helped channelize pedestrian traffic; however, they proved to be unable to persuade pedestrians to comply with the signal indication (low signal compliance). Both the actual movement and the survey data supported this conclusion.
- Approximately three-fourths of the users favored the pedestrian signals and the midblock crosswalks. Therefore, signalized and midblock crosswalks can be deployed with confidence wherever they are found to be necessary by traffic engineering analysis.
- The most influential factor cited by the pedestrians in making a decision to cross at a designated location was the distance of the crosswalk to the desired destination. Convenience was rated as the number one factor for jaywalking. These results indicate that proper selection of the position of a

crosswalk, with respect to land uses that generate or attract pedestrian traffic, has the potential to increase pedestrian compliance. If facilities are properly located, user compliance can be increased by approximately 10 to 35% compared to base conditions.

- Pedestrians disapproved of the use of the pedestrian warning signs at the midblock crosswalks, as they believed that it conveyed a confusing message. Additional crash and conflict analyses are recommended to clearly assess the value of these signs and provide guidelines for their use.
- Many survey respondents (52.4%) reported that the majority of turning vehicles failed to give priority to pedestrians when pedestrians are available in the crosswalks during pedestrian green phase. This increases the chances that pedestrians will not select to cross at signalized crosswalks during green if they have a crossing alternative that reduces their delays and provides safer crossing conditions. To improve the situation, leading or exclusive pedestrian phasing scheme needs to be considered when significant turning vehicle and pedestrian crossing volumes exist. Such pedestrian phasing plans are expected to assist in reducing the number of conflicting movements and improve safety as well as pedestrian crossing compliance. Significant enhancement of pedestrian traffic flow conditions may be possible through signal coordination (Virkler, 1998).

- Careful design of signal phasing plans and proper installation of signs can greatly help to improve travel conditions for pedestrians and turning motorists alike. Furthermore, it is recommended that additional surveys be conducted to examine differences between drivers and pedestrians regarding the right-of-way at intersections.

It should be noted that, although user preferences are important, they might not be highly correlated with safety considerations. It is recommended that additional analysis be performed to examine the relationship between safety and pedestrian acceptance in future research.

Chapter 6 concentrated on pedestrians' perceptions and preferences with respect to the use of pedestrian facilities. It is also important to know how motorists perceive pedestrian-vehicle interactions. A motorist survey to collect information along these lines at the study site is desirable.

Chapter 7

SAFETY ANALYSIS OF CROSSING OPTIONS

7.1. Introduction

Pedestrian deaths are mainly a problem in urban settings. Many pedestrians are killed in crosswalks, sidewalks, median strips, and traffic islands. The following statistics are based on data from Fatality Analysis Reporting System (FARS) (*Pedestrian Accident Statistics, online*, 1999). 69 percent of pedestrian deaths in 1996 occurred in urban areas. However, the ratio of deaths to injuries is higher in rural areas because of higher impact speeds on rural roads. 33 percent of pedestrian deaths among people age 65 and older in 1996 occurred at intersections. Moreover, 12 percent of pedestrian deaths occurred among children age 4 and younger. FARS contains data on all vehicle crashes in the United States that occur on a public roadway and involve a fatality in the crash.

A majority of the pedestrian-vehicle accidents in 1996 (82%) occurred in urban areas. Approximately 25 percent of pedestrians were killed or injured while crossing or entering intersections (*Pedestrian Accidents Statistics, online*, 1999). It should be noted that the vast majority of pedestrian accidents were caused by pedestrian violations of right-of-way (e.g., crossing during DONT WALK signal, crossing at a non-designated crossing area, and crossing without observing the right-of-way).

In the previous chapters of this study, the crossing options on Grand River Avenue were evaluated from the perspectives of pedestrian traffic operations, and pedestrian perceptions and preferences. This chapter provides an insight on safety of various pedestrian crossing options. The objectives of this chapter are: 1. to analyze pedestrian related crashes; and 2. to determine the effectiveness of various crossing locations with respect to safety. Such locations include signalized and unsignalized intersections and midblock crossing locations.

First, pedestrian related crash data from the study site are reviewed and presented for periods before and after the street renovations. Then, pedestrian crash data from the entire state of Michigan are reviewed and discussed.

7.2. Methodology

7.2.1. Before-and-After Analysis

Historical crash data used in this study were obtained from the computerized crash files prepared by the Michigan Department of Transportation and Michigan State Police for the years of 1988 through 1998. Pedestrian crash data for the study site were extracted from the crash files with the control section number of 33082 (Grand River Avenue, East Lansing) and the mile points of 1.190 and 1.820 (Abbott and Bogue Streets) for a 10-year period (from 1988 to 1998). SPSS statistical software package was used in data analysis.

In order to determine the effect of street renovations and improvements of pedestrian facilities and signalization on pedestrian safety, a before-and-after analysis was employed. Renovations on Grand River Avenue were started in 1994 and final signalization work was completed in 1996. The before period data include pedestrian crashes from 1988 to the end of 1993, and the after period data included crashes after all renovations and signalization work were completed (years 1997 and 1998). It should be noted that the after period is short in length of time (two years). Thus, it is advisable to check with the crash data in the future to verify the conclusions to be presented below with additional data. Data used in this analysis were crosstabulated by highway location and intersection traffic control type. A *t*-test can be performed to test whether there is a difference between the number of pedestrian and/or total crashes between the before and after periods. If one wishes to compare crashes from before, during and after periods, an analysis of variance (ANOVA) test can be utilized.

7.2.2. Safety Analysis of Crossing Options

In order to study the relative safety of various crossing options, pedestrian related crashes from the state of Michigan over a five-year period (1994-1998) were retrieved and analyzed. The data were crosstabulated by highway location (intersection/interchange, midblock, etc.) and intersection traffic control type (signal, yield and stop signs, etc.). Analysis of variance (ANOVA) test can be used to test the hypothesis that average crash rates for different types of crossing locations are equal.

7.3. Analysis and Results

7.3.1. Analysis of Pedestrian Crash Data for the Study Site

The crash data for Grand River Avenue between Abbott and Bogue Streets are summarized in Table 7.1 and graphically illustrated in Figure 7.1.

Looking at Table 7.1 and Figure 7.1, a gradual decrease in both total and pedestrian crashes can be seen from 1988 to 1998 except during the first two-

Table 7.1. Pedestrian crash data for the study site*

Years		Crashes									
		All^		Pedestrian							
		Total	Injury	Tot	Injury	Intersection					Mid-block
						Signal	Yield	Stop	None	Total	
Before period	'88	179	53	11	11	8	0	3	0	11	N/A+
	'89	175	46	7	7	2	0	2	3	7	N/A
	'90	158	38	2	2	0	0	0	2	2	N/A
	'91	137	34	3	3	2	0	0	1	3	N/A
	'92	140	47	1	0	1	0	0	0	1	N/A
	'93	136	36	2	2	2	0	0	0	2	N/A
Total		925	254	26	25	15	0	5	6	24	N/A
Average		154.2	42.3	4.3	4.2	2.5	0.0	0.8	1.0	4.0	N/A
Median		149.0	42.0	2.5	2.5	2.0	0.0	0.0	0.5	2.5	N/A
During period	'94	166	37	9	9	3	0	2	4	9	0
	'95	150	35	11	11	5	0	3	3	11	0
	'96	108	34	4	4	1	0	1	2	4	0
Total		424	106	24	24	9	0	6	9	24	0
Average		141.3	35.3	8.0	8.0	3.0	0.0	2.0	3.0	8.0	0.0
Median		150.0	35.0	9.0	9.0	3.0	0.0	2.0	3.0	9.0	0.0
After period	'97	144	33	1	1	1	0	0	0	1	0
	'98	90	20	4	4	1	0	1	2	4	0
Total		234	53	5	5	2	0	1	2	5	0
Average		117.0	26.5	2.5	2.5	1.0	0.0	0.5	1.0	2.5	0.0
Median		117.0	26.5	2.5	2.5	1.0	0.0	0.5	1.0	2.5	0.0

*: No fatal crashes are reported.
^: All crashes on the study site.
+: N/A: Not applicable. During the before period, there were no designated midblock crosswalk locations on Grand River Avenue.

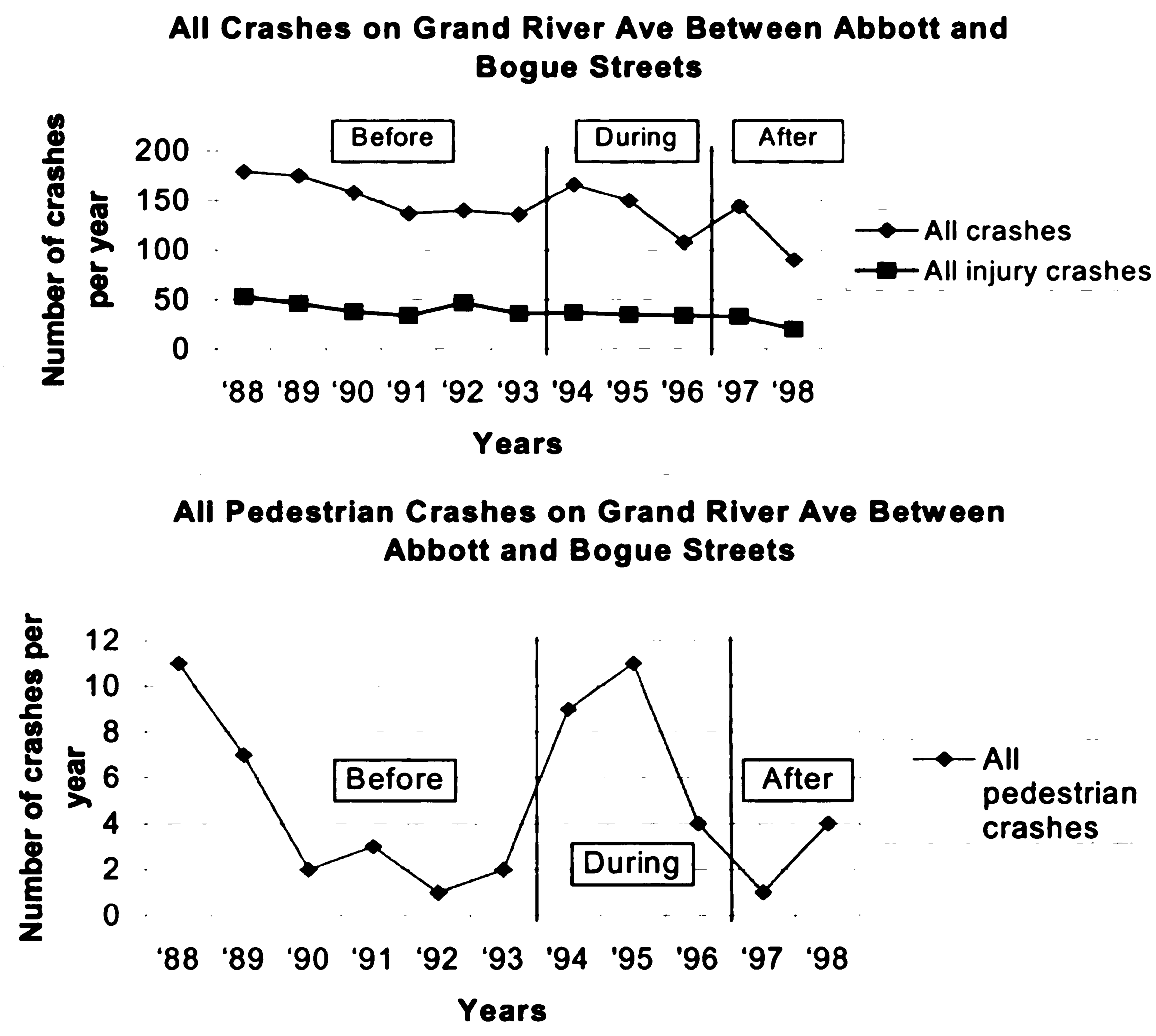


Figure 7.1. Total, all injury and pedestrian crashes on the study section

years of the construction period. Due to the small sample sizes for "during" and "after" periods and high variances in the crash data, it is decided to compare median values instead of averages. Comparison of the median of total crashes at the study site before and after renovations reveals a decrease of 21.5% in crashes (decrease from 149.0 crashes/year during the before period to 117.0 crashes/year during the after period). Similarly, the average number of injuries during the after period is 36.9% lower than that during the before period (decreased from 42.0 crashes/year during the before period to 26.5 crashes/year during the after period). Interestingly, the median of the total pedestrian crashes during the before and after periods was not changed significantly (2.5 crashes/year). Therefore, it seems that the number of average pedestrian crashes during the before period is not necessarily higher than that of the after period.

It should be noted once again that the pedestrian crash data for the study site do not allow for making statistically sound statements with respect to the relative safety of the crossing options due to inadequate sample sizes with the data disaggregated by intersection traffic control type. However, the lack of midblock pedestrian crashes indicating that midblock locations seem to be safe options is evident. A reason for this is that potential pedestrian-vehicle conflict points at midblock locations are less in number compared to those at intersections. Also, pedestrians crossing the street at the midblock crosswalks of the study site are alerted by a sign saying that "cross only when traffic clears." Moreover, pedestrians crossing the street at the signalized intersection crosswalks share the same green phase with turning vehicles since the signalized intersections on Grand River Avenue have the combined phasing scheme for turning vehicles and pedestrians. This situation increases the potential of vehicle-pedestrian crashes if turning motorists fail to yield to pedestrians in the signalized intersection crosswalks. A correlation of turning vehicle-pedestrian accidents with the combined phasing scheme should be researched in a future study, when more after period crash data become available.

7.3.2. Analysis of Pedestrian Crash Data for the State of Michigan

Michigan pedestrian crashes are summarized in Tables 7.2 through 7.4 and in Figure 7.2. Figure 7.2 reveals that the number of all types of pedestrian accidents were not changed drastically during the five-year period.

Table 7.2. Pedestrian total crashes in the state of Michigan

Years	Number of total pedestrian crashes						
	Midblock	Accidents by traffic control type at intersections					Total
		Signal	Yield	Stop	Other	Total	
1994	1,096	654	13	369	1,640	2,676	3,812
1995	1,127	628	17	347	1,700	2,692	3,856
1996	1,054	728	16	323	1,632	2,699	3,789
1997	995	638	13	302	1,525	2,478	3,503
1998	1,149	688	16	327	1,480	2,511	3,700

Table 7.3. Pedestrian fatality crashes in the state of Michigan

Years	Number of pedestrian fatal crashes						
	Midblock	Accidents by traffic control type at intersection					Total
		Signal	Yield	Stop	Other	Total	
1994	86	21	0	7	72	100	190
1995	83	11	0	7	87	105	190
1996	77	16	0	13	85	114	191
1997	72	18	0	3	59	80	154
1998	86	14	0	9	63	86	173

Table 7.4. Pedestrian injury crashes in the state of Michigan

Years	Number of pedestrian injury crashes						
	Midblock	Accidents by traffic control type at intersections					Total
		Signal	Yield	Stop	Other	Total	
1994	965	589	13	337	1,444	2,383	3,383
1995	965	555	16	315	1,484	2,370	3,368
1996	912	645	14	277	1,407	2,343	3,291
1997	837	560	10	274	1,333	2,177	3,043
1998	981	594	15	291	1,291	2,191	3,208

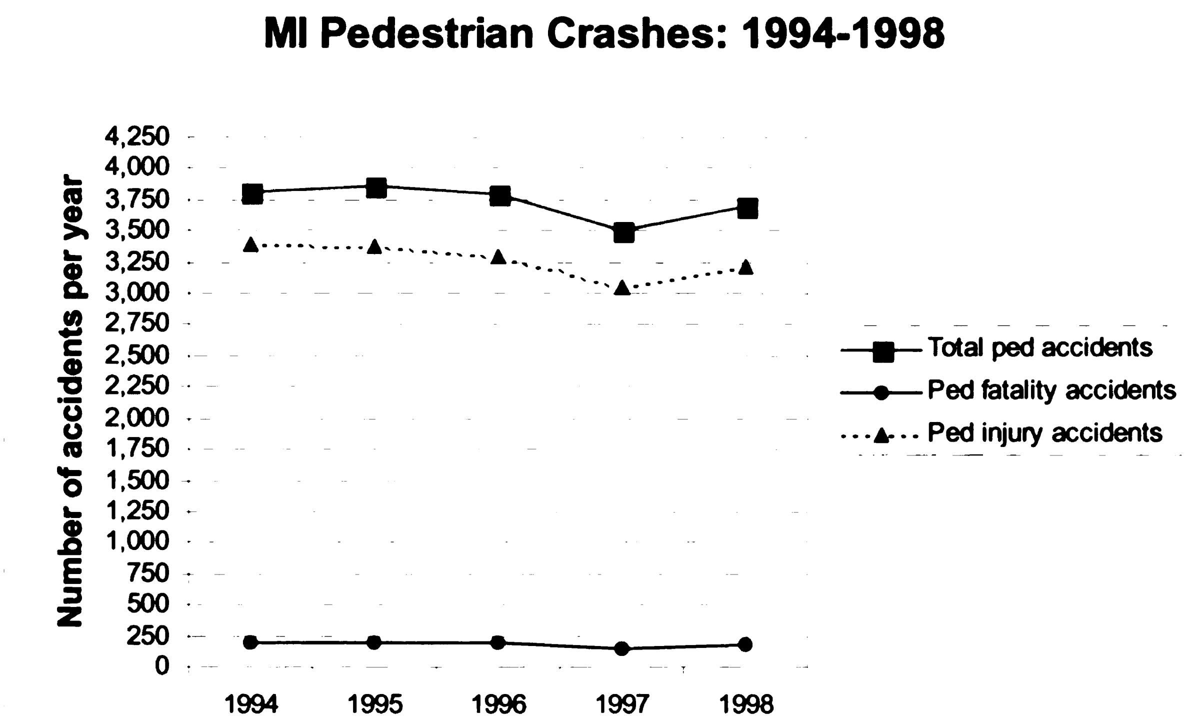
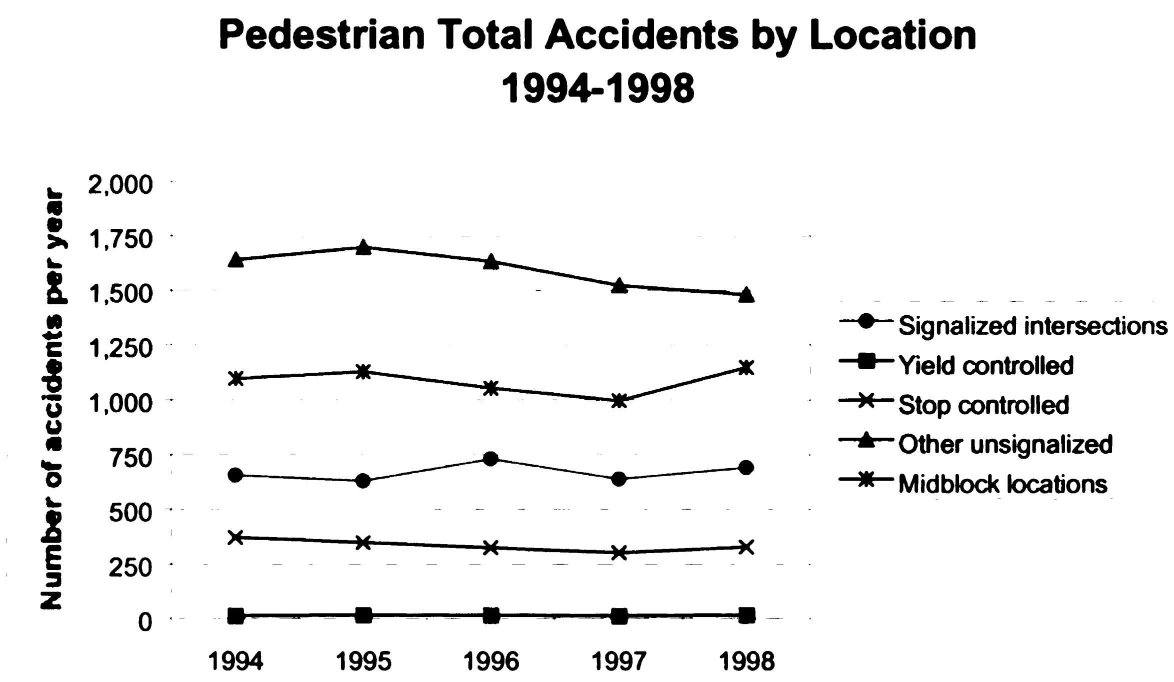


Figure 7.2. Summary of pedestrian crashes in Michigan (1994-1998)

In Figures 7.3.a and b, pedestrian total crashes in the state of Michigan are summarized by crossing location including signalized intersection, unsignalized intersection (stop, yield and other type of control) and midblock locations. The highest number and percent of pedestrian total crashes occurred in unsignalized intersections with non-existent traffic control. The lowest number and percent of pedestrian total crashes occurred in yield-controlled unsignalized intersections.



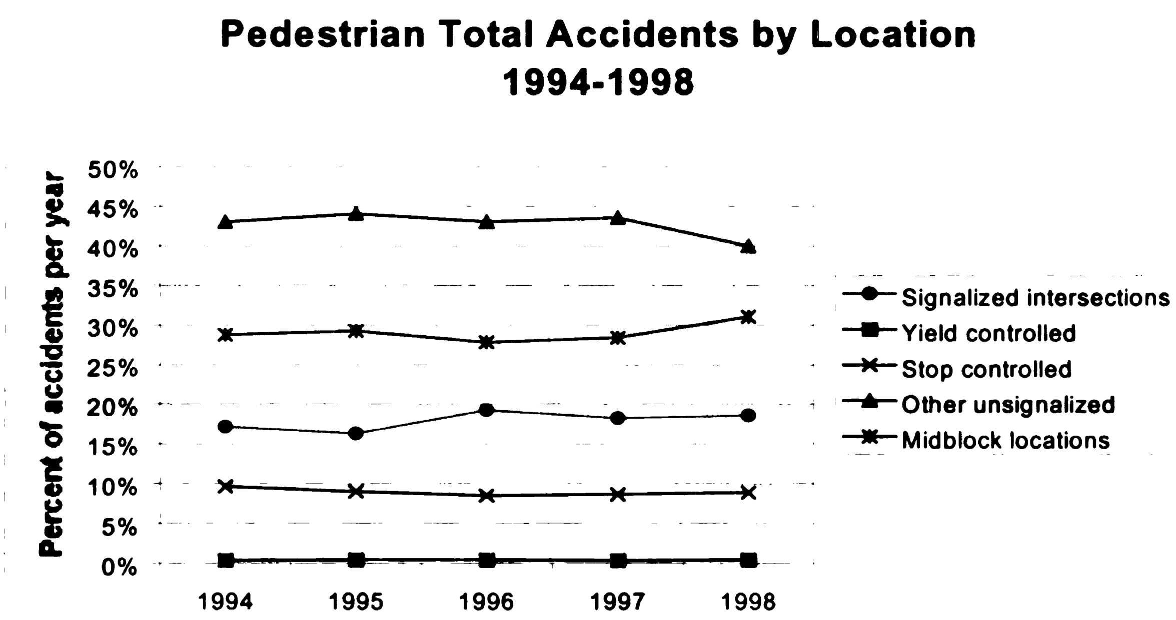


Figure 7.3.a and b. Pedestrian total crashes from 1994 to 1998

Based on Figures 7.4.a and b, unsignalized intersections (without positive traffic control) and midblock locations yielded the highest number and percent of pedestrian fatality crashes. The number and percentages of pedestrian fatality crashes were the lowest at signalized and stop-controlled intersections. No fatality crashes were reported for yield-controlled intersections. Similar trends are reported in Figures 7.5.a and b where pedestrian injury crashes are plotted.

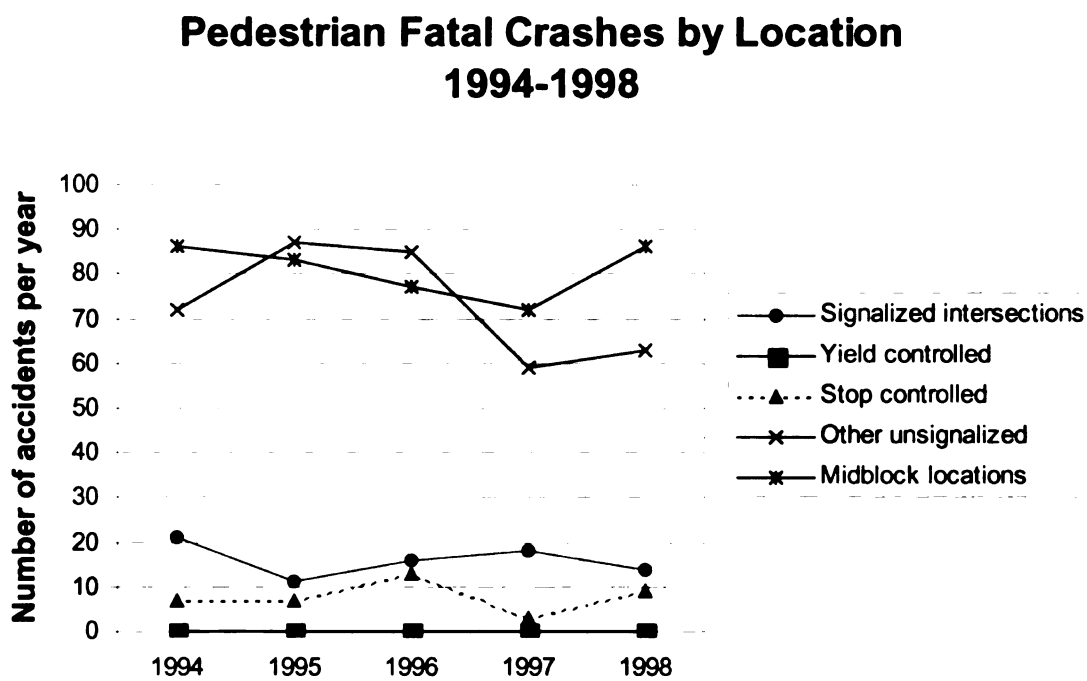


Figure 7.4.a. Pedestrian fatal crashes from 1994 to 1998

However, as stated earlier, such analyses can not allow for selection of crossing options that are safer than others as no information about exposure is provided such as pedestrian and vehicular traffic volumes. An improved approach for meaningful comparisons of various crossing options with respect to pedestrian safety is discussed next.

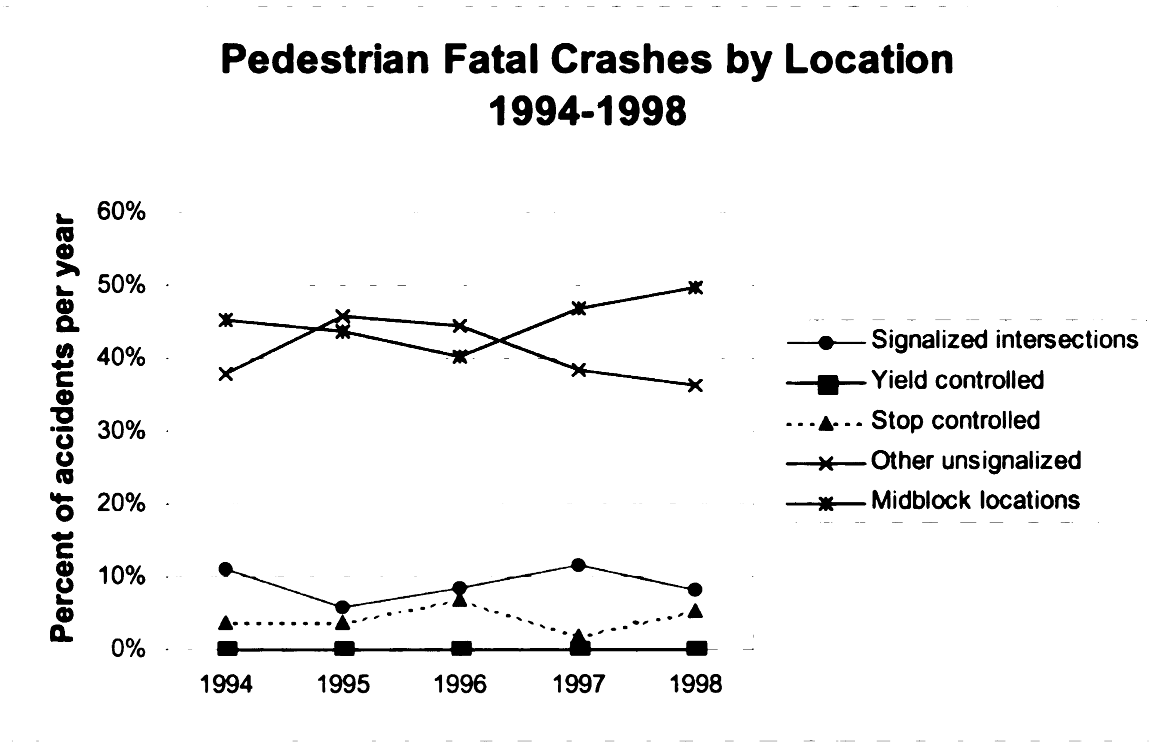


Figure 7.4.b. Percentages of pedestrian fatal crashes from 1994 to 1998

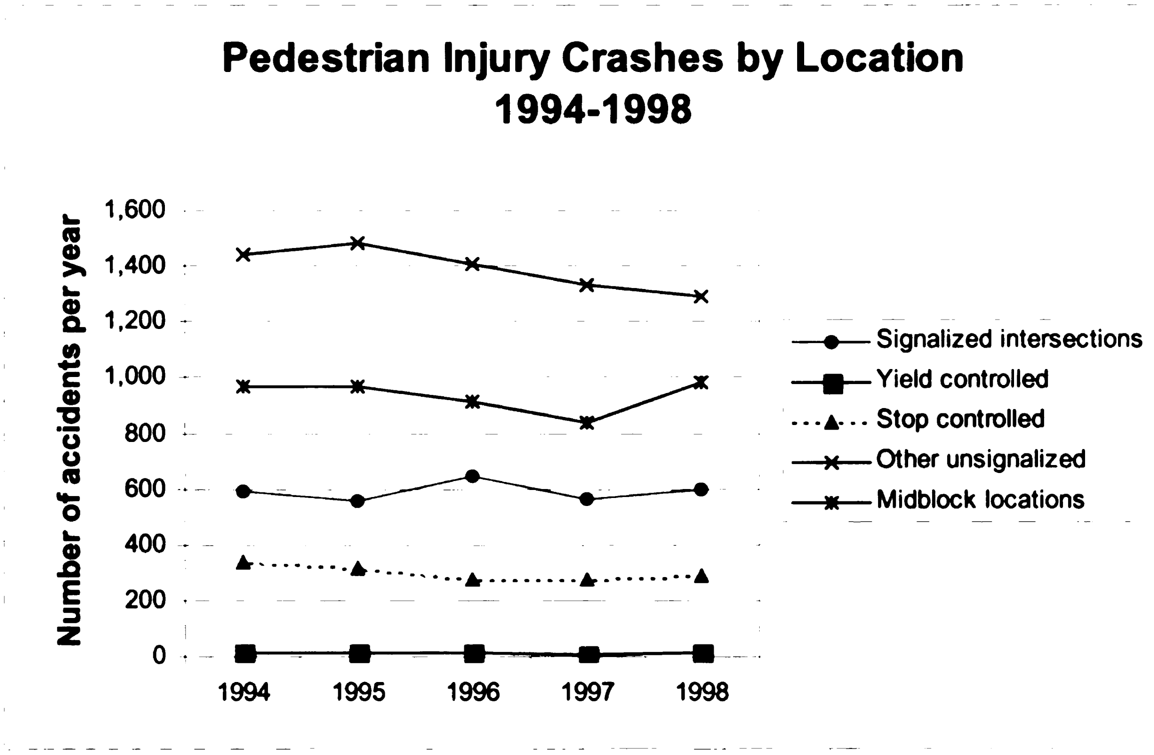


Figure 7.5.a. Pedestrian injury crashes from 1994 to 1998

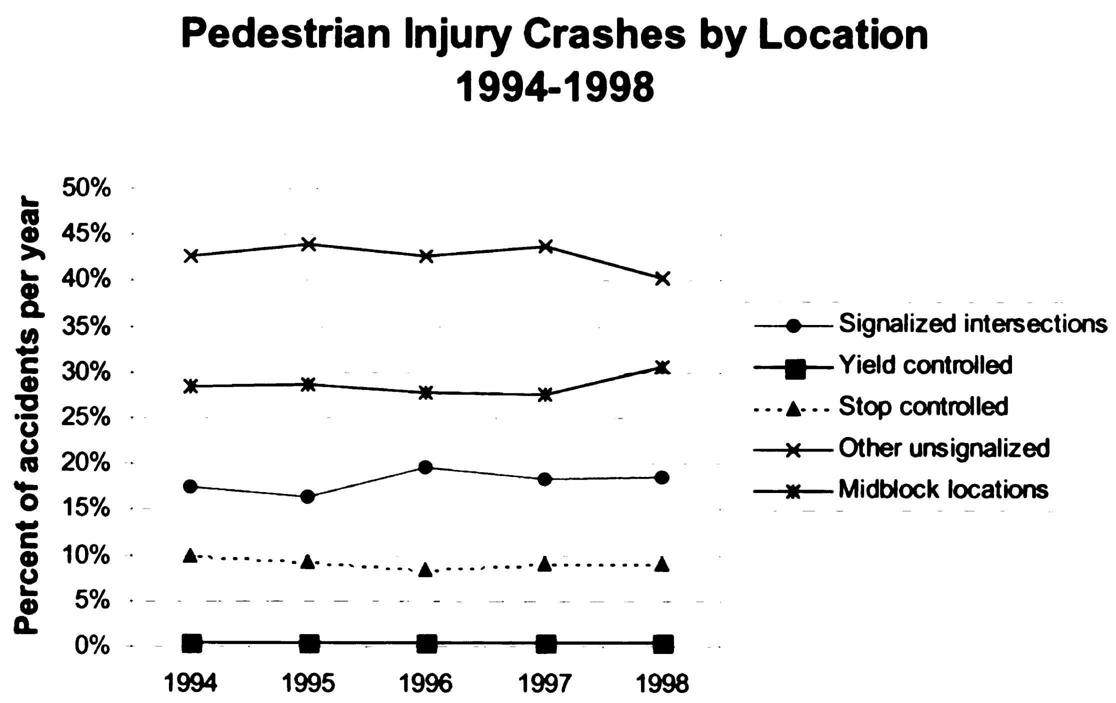


Figure 7.5.b. Percentages of pedestrian injury crashes from 1994 to 1998

7.3.3. Safety Analysis of Crossing Options

In order to properly determine which type of crossing location is safer, average daily pedestrian and vehicular traffic, and geometric characteristics of study sites should be taken under consideration. Instead of comparing the number or the percentage of crashes occurring in alternative crossing locations, it is more appropriate to compare pedestrian crash rates. Crash rates can be defined as the number of pedestrian crashes per million vehicles for spots and the number of pedestrian crashes per million vehicle-miles for a road section. In order to compare relative safety of crossing options, using crash frequencies or percentages alone does not account for the influence of vehicular and pedestrian traffic on the occurrence of crashes. However, crash rate includes some measures of exposure such as ADTs and length of the section. A crash rate is defined in order to consider vehicular and pedestrian traffic exposures. Equation 7.1 presents the formulation of the crash rate for a spot:

$$PCR = \frac{P.10^6}{365.N.(ADVT, ADPT, or\_both)} \cdots\cdots\cdots\cdots\cdots\cdots Eq.7.1$$

where

PCR = pedestrian crash rate (accidents per million vehicles and/or pedestrians),

P = number of reported pedestrian-vehicle crashes per year,

N = number of analysis years,

ADVT = average daily vehicular traffic (average number of vehicles entering the crosswalk per day), and

ADPT = average daily pedestrian traffic (average number of pedestrians entering the crosswalk per day).

7.3.3.1. Comparison of Crash Rates

Crash rates for total, fatal and injury (types of A, B and C) crashes can be used to compare the relative safety of the considered crossing locations, or crash rates can be adjusted to reflect higher costs of injury and fatal accidents. For this reason, property damage accidents can be used as a base type of accident. Other accidents, fatal and injury accidents, can be converted to the base type of accident using equivalency factors. This approach can overcome the problem of small sample sizes of certain types of accidents especially fatal ones.

The objective of comparing crash rates for pedestrian crossing options is to find out which type of location is the most hazardous. In addition to the number of crashes, information on volume (ADVT or ADPT) for each test site is needed. Volume and accident data should belong to same time period. Otherwise, volume data need to be adjusted by appropriate factors.

One-way analysis of variance (ANOVA) procedure is used to test the hypothesis that means of crash rates for different crossing locations are equal. The ANOVA procedure produces a one-way analysis of variance for a quantitative dependent variable (crash rate) by a single independent variable (type of crossing location). In addition to determining that differences exist among the means, it is possible to know which means differ. A priori contrasts test is the simplest one. Contrasts are tests set up before running the experiment. In the example of testing if crash rates are different for signalized and unsignalized intersections and midblock locations, the independent variable will be "type of crossing location" and coded as "1=signalized intersection," "2=unsignalized intersection," and "3= midblock location." The contrast coefficients will be (1, -0.5, -0.5) to test if crash rates at signalized intersections are different from the ones at the other two types of locations. The coefficients will be (-0.5, 1, -0.5) test if crash rates at unsignalized intersections are different from the ones at the other locations, and so on. Doing this contrast analysis, it is possible to say which locations are safer than others, and the locations can be ranked based on their relative safety of pedestrian. By examining the significance of differences between the means of crash rates for different crossing locations, the results of ANOVA procedure allows to determine whether the observed differences are statistically significant in the level of a desired confidence.

7.3.3.2. Alternative Method for Calculation of Crash Rates

It is a common practice use Equations 7.1 to compute accident rates. However, Hauer et al. (1988) claimed that in order to compute an overall intersection crash rate in Equation 7.1, using the total entering volume (ADVT) for an intersection is not a proper way because of the fact that left-turning movements are involved in accidents more frequently than through traffic. As an example, two identical intersections are considered with identical total entering volumes. One intersection has a high percentage of through traffic, while the other has a high percentage of left-turning movement. Because of the fact of a high accident involvement of left-turning vehicles, accident rate calculated using Equation 7.1 for the second intersection would be higher than that of the first intersection. However, this does not mean that the second intersection has a more correctable safety problem than the first intersection. Therefore, an alternative procedure needs to be utilized, which can take into account the types of traffic volumes rather than the overall entering volume (Robertson, et al., 1994).

Hauer et al. (1988) developed a procedure that can rank intersections by hazard and accounts for different types of movement volumes. The procedure uses the variable of motorists' intent instead of the variable of accident type because the former provides more information than the latter about the nature of the accident. For example, many accidents involving left-turning vehicles will have accident type coded as angle because the vehicles collided at right angles. Through and turning movement counts must be available for each location that is examined. The procedure is summarized in the *Manual of Transportation Engineering Studies* published by the Institute of Transportation Engineers (Robertson, et al., 1994, pp.206-8).

7.4. Summary and Conclusions and Recommendations for Future Research

In this chapter, pedestrian crashes occurring at various crossing locations in the study site are reviewed and discussed. The crash history of the study site does not provide usable information to reach to any conclusion or to make statistically reliable statements because of the low and dispersed number of pedestrian crashes. Therefore, using the available study site crash data, it is not possible to rank the crossing locations in the study site based on their relative safety. For this reason, it was decided to analyze pedestrian crashes that occurred on various types of pedestrian crossing locations in the state of Michigan. However, these data are not associated with traffic exposure data. For this reason, calculating crash rates is nearly impossible because associating exposure data with the number of crashes for the entire state of Michigan is also almost impossible. Therefore, the crash data cannot be used to rank the locations. It is suggested that ADT counts should be added to Michigan crash files for each accident. With this, it would be possible to calculate crash rates for various crossing locations (signalized intersection, unsignalized intersection, midblock, etc.) and rank the sites based on crash rates using an appropriate statistical method. In the final section of this chapter, performing a meaningful crash analysis using crash rates was summarized.

In a future research, a safety analysis can be conducted using ample before and after crash data with traffic exposure data (pedestrian and vehicle volumes) to compare relative safety of crossing locations on Grand River Avenue.

Chapter 8

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1. Summary and Conclusions

In this section, the summary and the conclusions of Chapter 3 through 7 are presented, respectively.

8.1.1. Chapter 3

In Chapter 3, the effectiveness of various crossing options was assessed through the study of pedestrian crossing activity along Grand River Avenue between Abbott and Bogue Streets. The measure of effectiveness used to compare the pedestrian crosswalks was the pedestrian crossing compliance. Some important conclusions were summarized as follows:

- A positive type of traffic control affects pedestrian crossing compliance positively with respect to the crossing location. The highest pedestrian spatial compliance rates were observed at the signalized intersection crosswalks (average PCR = 83.13%), followed by the marked midblock crosswalks (71.19%).
- Pedestrian spatial crossing compliance was greater at the midblock crosswalks than the unsignalized intersection crosswalks. Thus marked midblock crosswalks should be used with confidence when needed, e.g., in long blocks when the land use in midblock locations generates or

attracts high pedestrian flows, since a large majority of pedestrians appear to recognize and use them properly.

- Although the use of the shelters as means to increase the pedestrian crossing safety is not verified, they can be used to improve the esthetics of crossing environments, which can help increase the qualitative level of service of pedestrian facilities according to the results of the studies conducted by Sarkar (1993) and Khisty (1993).
- Overall crossing compliance rates at the signalized intersection crosswalks was found to be low (with an average value of only 42.98%). This indicates that the majority of pedestrians crossing at the signalized crosswalks violate the pedestrian WALK signal.
- Barriers located between the sidewalks and the roadway seemed to increase spatial crossing compliance rate.

8.1.2. Chapter 4

In Chapter 4, pedestrian crossing times and the quantitative level of service (LOS) estimations at the signalized intersection crosswalks were studied in detail. The existing methodologies for the estimation of pedestrian crossing times were reviewed and summarized. These methodologies were validated using measured pedestrian crossing times collected at the study crosswalks. The data were collected at all the four signalized intersection crosswalks within the study area during the vehicular traffic off-peak and the PM-peak conditions. The measured pedestrian crossing time data were used to check if the current signal settings at the site meet the minimum green and flashing red requirements for pedestrians. Additionally, the measured crossing times were used to assess the pedestrian LOS at the signalized crosswalks. The following conclusions were reached based on the results of the analyses:

- The existing methodologies for pedestrian crossing time estimation systematically overpredicted the pedestrian crossing times in the study site. Refinement of such methodologies is recommended so that they represent actual conditions in a more realistic manner.
- Pedestrian crossing time is a key measure to the evaluation of pedestrian signal settings and to the assessment of operational efficiency at signalized intersections from the perspective of pedestrian users.
- Pedestrian crossing times can assist proper selection of signal settings, including pedestrian green and flashing red interval lengths. Therefore, pedestrian crossing times should be determined or estimated properly in order to design efficient signal timing for pedestrians as well as for vehicles.
- The existing pedestrian interval lengths (WALK and flashing DON'T WALK times) are found to be sufficient to provide safe and comfortable pedestrian crossing activities at the signalized crosswalks. The minimum pedestrian clearance (flashing red) time criterion is met at all the locations.
- All the signalized intersection crosswalks in the study area operate at the acceptable pedestrian level of service (LOS B or better) during both the off-peak and the PM-peak conditions.

- Turning vehicles at the signalized intersections did not significantly affect the pedestrian LOS values in the crosswalks.

8.1.3. Chapter 5

In Chapter 5, pedestrian-turning vehicle interactions at the signalized intersection crosswalks were studied in detail. First, potential pedestrian conflicts with right- and left-turning vehicles at the signalized intersection crosswalks were defined and measured at the signalized locations within the study area. The total number of potential turning vehicle-pedestrian conflicts observed was used to classify the study intersections with respect to the need for improvements. Potential conflict estimation models were developed and discussed. The proposed models can be used to estimate potential right- and left- turning vehicle-pedestrian conflicts when turning vehicle and pedestrian volumes are available. Determining the conflicts provides traffic engineers information about the potential hazard of intersections with the defined conflicts. If the number of the conflicts is significantly higher compared to similar locations, then safety precautions need to be taken in order to reduce the number of the conflicts by implementing early/late release of vehicles/pedestrians.

The following conclusions were reached from the results of the analyses described in Chapter 5:

- The estimation of potential right- and left-turning vehicle-pedestrian conflicts is possible through the application of the regression models developed in this study.

- The models indicated that the product of pedestrian and turning vehicle volumes is highly correlated with the pedestrian conflicts with turning vehicles at the signalized intersection crosswalks.

8.1.4. Chapter 6

In Chapter 6, the procedure used to obtain information on pedestrian users' preferences and perceptions was described, and the results from the survey analysis were analyzed. The analysis of survey data provided important insights on the attitudes and preferences of the pedestrians using the study site. The following conclusions are to be drawn from the analysis of the survey data:

- Properly marked pedestrian facilities encourage users to cross at certain locations. More specifically, the marked midblock crosswalks were found to be very influential pedestrian facilities. This conclusion was also supported by the analysis of the movement data presented in Chapter 3.
- The signalized intersections with pedestrian crosswalks helped channelize pedestrian traffic; however, they proved to be unable to persuade pedestrians to comply with the signal indication (yielded low signal compliance).
- Approximately three-fourths of the users favored the pedestrian signals and the midblock crosswalks. Therefore, signalized and midblock crosswalks can be deployed with confidence in high user compliance wherever they are found to be necessary by traffic engineering analysis.

- The most influential factor cited by the pedestrians in making a decision to cross at a designated location was the distance to a desired destination. Crossing convenience was rated as the number one factor for jaywalking (not choosing to cross at a designated crossing location). These results indicate that the proper selection of the position of a crosswalk, with respect to the landuse that generate or attract pedestrian traffic, has the potential to increase spatial crossing compliance. If facilities are properly located, user compliance can be increased by approximately 10 to 35% compared to base conditions.
- Pedestrians disapproved of the use of the pedestrian warning signs (messaging "cross only when traffic clears") at the midblock crosswalks, as they believed it conveyed a confusing message. Additional crash and conflict analyses are recommended to clearly assess the value of this sign and provide guidelines for its use.
- Many survey respondents (52.4%) reported that the majority of turning vehicles failed to give priority to pedestrians crossing during pedestrian green phase. This increases the chances that pedestrians will not select to cross at signalized crosswalks during green if they have a crossing alternative that reduces their delays and provides safer crossing conditions. To improve the situation, leading/lagging or exclusive pedestrian phasing scheme needs to be considered when significant turning vehicle and pedestrian crossing volumes exist simultaneously.

- Based on the literature review, alternative pedestrian phasing plans are expected to assist in reducing the number of conflicting movements and to improve safety and user compliance. Furthermore, careful design of signal phasing plans and proper installation of signs can greatly help to improve travel conditions for both pedestrians and turning motorists alike. Significant enhancement of pedestrian traffic flow along major corridors could also be possible through traffic signal coordination (Virkler, 1998).

8.1.5. Chapter 7

In Chapter 7, the pedestrian crashes occurring at various crossing locations in the study site and in the entire state of Michigan were presented and reviewed. It was seen that the pedestrian crash data on the study site were limited due to the shortness of the "after" construction period. In addition, the data are dispersed and do not provide an insight to reach reasonable conclusions. For this reason, it was decided to analyze the pedestrian crashes, which occurred on various types of pedestrian crossing locations in the state of Michigan. Although there were ample data, due to the lack of exposures again it was not meaningful to compare the sites based on the plain number and percent of accidents. Because without the exposure data (e.g., pedestrian and vehicular volumes) as well as geometric features of locations, comparing the number of accidents occurring on candidate locations does not disclose any information of whether unsignalized intersections, for example, are safer than signalized ones even if unsignalized intersections have fewer accidents than signalized ones. In the final section of this chapter, performing a meaningful crash analysis using crash rates was summarized.

8.2. Recommendations for Future Research

8.2.1. Chapter 3

In Chapter 3, the assessment of pedestrian crosswalks based on user compliance was conducted. The data collected on a 1-km long urban boulevard were limited in terms of different pedestrian signal timing and phasing schemes. Therefore, the effect of different signal timings and phasing plans on pedestrian compliance was not studied. Effect of signal timing and phasing schemes at signalized intersections, and signal progression along a corridor on pedestrian crossing compliance should be studied in a future study. By doing so, necessary adjustments can be done to encourage pedestrians to comply with pedestrian signals.

8.2.2. Chapter 4

The research summarized in Chapter 4 focused on the validation of the existing methodologies to estimate pedestrian crossing time and calculate pedestrian LOS at signalized crosswalks. All these methodologies overestimated observed crossing times at the signalized intersection crosswalks on Grand River Avenue. It is believed that the formulas overstate the length of start-up delay (perception-reaction time, *D*) for the pedestrians by utilizing the values of *D* from 4 sec to 7 sec. The field observations indicated that this value was in the range of

3 sec to 4 sec for the pedestrians studied. Secondly, none of the formulas considers two-way platoon movements. The consideration of two-way platoons is very important for the application of the formulas in places where high bi-directional pedestrian volumes are observed such as in downtown of metropolitan areas. Thirdly, none of the formulas considers the effect of turning-vehicles on individual pedestrians and platoons of pedestrians. All the formulas are valid under the conditions of a little interaction between pedestrians and turning vehicles. Lastly, design (walking) speed, start-up delay and headway between pedestrians should reflect the characteristics of local users in designing signalized crosswalks in order not to increase delay for vehicles by allowing an excessive green and flashing red time for pedestrians. All these issues should be further researched and addressed by specialized studies.

8.2.3. Chapter 5

The following recommendations were made for future researches based on the results of the subject study in Chapter 5:

- Although the regression models proposed in this chapter yield very reasonable results, additional testing of the models is recommended to confirm their validity and applicability in different settings.
- The models estimating potential pedestrian conflicts with turning vehicles were developed using the data for the combined pedestrian-vehicle phasing only. For other pedestrian signal phasing schemes

(e.g., early or late release), the same models can be tested and/or different parameters/models can be developed.

- The relationship between pedestrian crashes and pedestrian-vehicle conflicts was not studied in detail. A future study should analyze this relationship.

8.2.4. Chapter 6

Based on the findings from the analyses covered in Chapter 6, the following recommendations for future researches are made:

- Additional crash and conflict analyses are recommended to clearly assess the value of the pedestrian warning sign (messaging "cross only when traffic clears") at midblock crosswalk locations and provide guidelines for its use.
- It is recommended that additional surveys be conducted to examine differences between drivers and pedestrians regarding the right-of-way at intersections.
- It should be noted that, although user preferences are important, they might not be highly correlated with safety considerations. It is recommended that additional analysis be performed to examine the relationship between safety and pedestrian acceptance in a future research.
- Chapter 6 concentrated on the perceptions and preferences of the users of the pedestrian facilities on Grand River Avenue. A future study should

analyze the perceptions and preferences of drivers who use the study section regularly because motorists' opinions toward pedestrian facilities are as important as pedestrians' are. However, for this type of survey, locating the target population could not be an easy task.

8.2.5. Chapter 7

In a future research, a pedestrian safety analysis in crosswalks should be conducted using ample before and after crash data with related exposures (pedestrian and vehicle volumes) to compare the relative safety of the crossing locations on Grand River Avenue.

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APPENDICES

APPENDIX A: Summaries of Pedestrian Movement Data

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/23/99, Monday, 35 F, cold, partly sunny **Time:** 2:46p

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts-30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	47	2	0	11	**49**
PS (VR)	14	1	0	2	**15**
S	32	2	2	3	**36**
LS	9	1	0	1	**10**
Total	**102**	**6**	**2**	**17**	**110**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 110 + 5 + 3 = 118 peds in 30 min
Vehicular Volume (VV) = 2427 veh/hr L_{CIA} = 38.4 m (126.0 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{47}{118}$$

= 39.8%

Total pedestrian volume in the crosswalk area = 118 * 2 = 236 peds / hr
Compliance to location only = 86.44% Violation of flashing red signal = 9.09%
Compliance to signal only = 44.55%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count-30min	45	5	4	54

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 54 + 0 + 2 = 56 peds in 30 min
Vehicular Volume (VV) = 2418 veh/hr L_{CIA} = 85.50 m (280.5 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{45}{56}$$

= 80.4%

Total Pedestrian Volume in the Crosswalk Influence Area = 56 * 2 = 112 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT – BOGUE STS)

Date: 2/23/99, Monday, 35 F, cold, partly sunny **Time:** 2:46p

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	15	5	1	6	**21**
PS (VR)	15	1	1	2	**17**
S	13	3	0	1	**16**
LS	8	2	0	2	**10**
Total	**51**	**11**	**2**	**11**	**64**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 8 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 64 + 8 + 1 = 73 peds in 30 min
Vehicular Volume (VV) = 2312 veh/hr L_{CIA} = 97.25 m (319.06ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{15}{73} = 20.5\%$$

Total pedestrian volume in the crosswalk area = 73 * 2 = 146 peds / hr
Compliance to location only = 69.86% Violation of flashing red signal = 15.63%
Compliance to signal only = 32.81%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	14	4	2	20

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 20 + 2 + 3 = 25 peds in 30 min
Vehicular Volume (VV) = N/A veh/hr L_{CIA} = 71.95 m (236.06ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{14}{25} = 56.0\%$$

Total pedestrian volume in the crosswalk area = 25 * 2 = 50 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/23/99, Monday, 35 F, cold, partly sunny **Time:** 2:46p

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count-30 min	29	10	1	40

Jaywalkers from west side of the crosswalk = 6 peds in 30 min

Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 40 + 6 + 7 = 53 peds in 30 min
Vehicular Volume (VV) = N/A veh/hr L_{CIA} = 97.85m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{29}{53} = 54.7\%$$

Total pedestrian volume in the crosswalk area = 53 * 2 = 106 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	70	1	1	4	**72**
PS (VR)	18	0	0	0	**18**
S	19	12	1	8	**32**
LS	17	0	0	1	**17**
Total	**124**	**13**	**2**	**13**	**139**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 13 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 139 + 13 + 6 = 158 peds in 30 min
Vehicular Volume (VV) = N/A veh/hr L_{CIA} = 96.0 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{70}{158} = 44.3\%$$

Total pedestrian volume in the crosswalk area = 158 * 2 = 316 peds / hr
Compliance to location only = 78.48% Violation of flashing red signal = 12.23%
Compliance to signal only = 51.80%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/28/98, Thursday, mid 70 F, sunny **Time:** 3:15p

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	7	0	0	4	**7**
PS (VR)	10	1	0	0	**11**
S	5	0	0	4	**5**
LS	6	0	0	3	**6**
Total	**28**	**1**	**0**	**11**	**29**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 29 + 0 + 3 = 32 peds in 30 min
Vehicular Volume (VV) = 2168 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{7}{32}$$
= 21.9%

Total pedestrian volume in the crosswalk area = 32 * 2 = 64 peds / hr
Compliance to location only = 87.50% Violation of flashing red signal = 20.69%
Compliance to signal only = 24.14%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	12	2	1	15

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 15 + 1 + 1 = 17 peds in 30 min
Vehicular Volume (VV) = 2184 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{12}{17}$$
= 70.6%

Total pedestrian volume in the crosswalk area = 17 * 2 = 34 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/28/98, Thursday, mid 70 F, sunny **Time:** 3:15p

3- M.A.C. Ave. Signalized Intersection Crosswalk

Signalized	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	15	0	0	2	**15**
PS (VR)	7	2	0	0	**9**
S	2	1	0	3	**3**
LS	6	0	0	2	**6**
Total	**30**	**3**	**0**	**7**	**33**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 33 + 2 + 1 = 36 peds in 30 min
Vehicular Volume (VV) = 2223 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} \quad \frac{15}{36} = 41.7\%$$

Total pedestrian volume in the crosswalk area = 36 * 2 = 72 peds / hr
Compliance to location only = 83.33% Violation of flashing red signal = 18.18%
Compliance to signal only = 45.45%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	7	1	0	8

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 8 + 2 + 2 = 12 peds in 30 min
Vehicular Volume (VV) = 2198 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{7}{12} = 58.3\%$$

Total pedestrian volume in the crosswalk area = 12 * 2 = 24 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/28/98, Thursday, mid 70 F, sunny **Time:** 3:15p

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrians	12	0	2	14

Jaywalkers from west side of the crosswalk = 2 peds in 30 min

Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 14 + 2 + 2 = 18 peds in 30 min
Vehicular Volume (VV) = 2156 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{12}{18} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 18 * 2 = 36 peds / hr

6- Division St. Signalized Intersection Crosswalk

Signalized	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	28	0	0	2	**28**
PS (VR)	7	0	0	0	**7**
S	6	1	0	2	**7**
LS	4	0	0	1	**4**
Total	**45**	**1**	**0**	**5**	**46**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)
Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 46 + 2 + 6 = 54 peds in 30 min
Vehicular Volume (VV) = 2337 veh/hr L_{CIA} = 96 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{28}{54} = 51.9\%$$

Total pedestrian volume in the crosswalk area = 54 * 2 = 108 peds / hr
Compliance to location only = 83.33% Violation of flashing red signal = 8.70%
Compliance to signal only = 60.87%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT – BOGUE STS)
Date: 2/10/98, Tuesday, Low 40 F, warm **Time:** 10:43a

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	23	1	0	2	**24**
PS (VR)	5	0	0	1	**5**
S	8	1	0	5	**9**
LS	11	0	0	1	**11**
Total	**47**	**2**	**0**	**9**	**49**

RU: Regular users
S: Sneakers
PS (VS): Partial sneakers (vehicles stopped)
LS: Late starters
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 4 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 49 + 4 + 0 = 53 peds in 30 min
Vehicular Volume (VV) = 1526 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{23}{53} = 43.4\%$$

Total pedestrian volume in the crosswalk area = 53 * 2 = 106 peds / hr
Compliance to location only = 88.68% Violation of flashing red signal = 22.45%
Compliance to signal only = 48.98%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	20	6	1	27

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 10 peds in 30 min
Total pedestrians in the crosswalk area = 27 + 0 + 10 = 37 peds in 30 min
Vehicular Volume (VV) = 1746 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{20}{37} = 54.1\%$$

Total pedestrian volume in the crosswalk area = 37 * 2 = 74 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/10/98, Tuesday, Low 40 F, warm **Time:** 10:43a

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	45	2	0	4	**47**
PS (VR)	38	2	0	4	**40**
S	19	2	0	1	**21**
LS	11	1	0	0	**12**
Total	**113**	**7**	**0**	**9**	**120**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 7 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 120 + 7 + 7 = 134 peds in 30 min
Vehicular Volume (VV) = 1833 veh/hr L_{CIA} = 97.25 m (319.06 ft)

Overall compliance rate = *No of RUs + no PS(VS)s on-crosswalk* / *Total peds in the crosswalk area* = 45 / 134 = 33.6%

Total pedestrian volume in the crosswalk area = 36 * 2 = 72 peds / hr
Compliance to location only = 84.33% Violation of flashing red signal = 10.00%
Compliance to signal only = 39.17%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	21	3	0	24

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 24 + 3 + 3 = 30 peds in 30 min
Vehicular Volume (VV) = 2198 veh/hr L_{CIA} = 71.95 m (236.06 ft)

Crossing compliance rate = *No of Pedestrians on-crosswalk* / *Total peds in the crosswalk area* = 21 / 30 = 70.0%

Total pedestrian volume in the crosswalk area = 30 * 2 = 60 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/10/98, Tuesday, Low 40 F, warm **Time:** 10:43a

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrians	79	12	3	94

Jaywalkers from west side of the crosswalk = 12 peds in 30 mins
Jaywalkers from east side of the crosswalk = 4 peds in 30 mins
Total pedestrians in the crosswalk area = 94 + 12 + 4 = 110 peds / hr
Vehicular Volume (VV) = 2230 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{79}{110} = 71.8\%$$

Total pedestrian volume in the crosswalk area = 110 * 2 = 220 peds / hr

6- Division St. Signalized Intersection Crosswalk

Signalized	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	149	3	0	5	**152**
PS (VR)	26	0	0	0	**26**
S	34	1	0	2	**35**
LS	24	2	0	2	**26**
Total	**233**	**6**	**0**	**9**	**239**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 239 + 3 + 7 = 249 peds in 30 min
Vehicular Volume (VV) = 2156 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{149}{249} = 59.8\%$$

Total pedestrian volume in the crosswalk area = 249 * 2 = 598 peds / hr
Compliance to location only= 93.57% Violation of flashing red signal= 10.88%
Compliance to signal only= 63.60%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)

Date: 2/14/98, Saturday, High 30 F, cold, partly cloudy **Time:** 12:44p

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	24	0	0	12	**24**
PS (VR)	5	1	0	2	**6**
S	7	1	0	3	**8**
LS	9	2	1	0	**12**
Total	**45**	**4**	**1**	**17**	**50**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 50 + 2 + 0 = 52 peds in 30 min
Vehicular Volume (VV) = 2540 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{24}{52} = 46.2\%$$

Total pedestrian volume in the crosswalk area = 52 * 2 = 104 peds / hr
Compliance to location only = 86.54% Violation of flashing red signal = 24.00%
Compliance to signal only = 48.00%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	32	10	1	43

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 43 + 0 + 2 = 45 peds in 30 min
Vehicular Volume (VV) = 2682 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{32}{45} = 71.1\%$$

Total pedestrian volume in the crosswalk area = 45 * 2 = 90 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT – BOGUE STS)
Date: 2/14/98, Saturday, High 30 F, cold, partly cloudy **Time:** 12:44p

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	19	2	0	2	**21**
PS (VR)	9	1	0	0	**10**
S	0	0	0	0	**0**
LS	1	0	0	1	**1**
Total	**29**	**3**	**0**	**3**	**32**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 32 + 5 + 2 = 39 peds in 30 min
Vehicular Volume (VV) = 2800 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{19}{39} = 48.7\%$$

Total pedestrian volume in the crosswalk area = 39 * 2 = 78 peds / hr
Compliance to location only = 74.36% Violation of flashing red signal = 3.13%
Compliance to signal only = 65.63%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	10	1	0	11

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 11 + 2 + 2 = 15 peds in 30 min
Vehicular Volume (VV) = 2441 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{10}{15} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 15 * 2 = 30 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/14/98, Saturday, High 30 F, cold, partly cloudy **Time:** 12:44p

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	21	2	0	23

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 23 + 3 + 5 = 31 peds in 30 min
Vehicular Volume (VV) = 2655 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{21}{31} = 67.7\%$$

Total pedestrian volume in the crosswalk area = 31 * 2 = 62 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian count- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	24	1	0	2	**25**
PS (VR)	2	0	0	0	**2**
S	3	0	0	2	**3**
LS	4	0	0	3	**4**
Total	**33**	**1**	**0**	**7**	**34**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 34 + 1 + 7 = 42 peds in 30 min
Vehicular Volume (VV) = 2602 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{24}{42} = 57.1\%$$

Total pedestrian volume in the crosswalk area = 42 * 2 = 84 peds / hr
Compliance to location only = 78.57% Violation of flashing red signal = 11.76%
Compliance to signal only = 73.53%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/26/98, Thursday, High 40 F, warm and sunny **Time:** 10:35a

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	13	4	0	1	**17**
PS (VR)	4	0	0	0	**4**
S	20	1	1	2	**22**
LS	2	1	0	0	**3**
Total	**39**	**6**	**1**	**3**	**46**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 46 + 0 + 2 = 48 peds in 30 min
Vehicular Volume (VV) = 1394 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{13}{48} = 27.1\%$$

Total pedestrian volume in the crosswalk area = 48 * 2 = 96 peds / hr
Compliance to location only = 81.25% Violation of flashing red signal = 6.52%
Compliance to signal only = 36.96%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	16	5	2	23

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 4 peds in 30 min
Total pedestrians in the crosswalk area = 19 + 1 + 4 = 24 peds in 30 min
Vehicular Volume (VV) = 1564 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{16}{24} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 24 * 2 = 48 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/26/98, Thursday, High 40 F, warm and sunny **Time:** 10:35a

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	55	3	0	4	**58**
PS (VR)	34	0	0	5	**34**
S	21	2	1	3	**24**
LS	7	1	0	0	**8**
Total	**117**	**6**	**1**	**12**	**124**

RU: Regular users
PS (VS): Partial sneakers (vehicles stopped)
PS (VR): Partial sneakers (vehicles running)
S: Sneakers
LS: Late starters

Jaywalkers from west side of the crosswalk = 8 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 124+ 8 + 6 = 138 peds in 30 min
Vehicular Volume (VV) = 1807 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{55}{138} = 39.9\%$$

Total pedestrian volume in the crosswalk area = 138 * 2 = 276 peds / hr
Compliance to location only = 84.78% Violation of flashing red signal = 6.45%
Compliance to signal only = 46.77%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	13	10	1	24

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 24 + 2 + 3 = 29 peds in 30 min
Vehicular Volume (VV) = 2091 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{13}{29} = 44.8\%$$

Total pedestrian volume in the crosswalk area = 29 * 2 = 58 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/26/98, Thursday, High 40 F, warm and sunny **Time:** 10:35a

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	58	12	2	72

Jaywalkers from west side of the crosswalk = 11 peds in 30 min
Jaywalkers from east side of the crosswalk = 8 peds in 30 min
Total pedestrians in the crosswalk area = 72 + 11 + 8 = 91 peds in 30 min
Vehicular Volume (VV) = 2192 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{58}{91} = 63.7\%$$

Total pedestrian volume in the crosswalk area = 91 * 2 = 182 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	189	7	0	7	**196**
PS (VR)	69	0	0	2	**69**
S	51	7	0	5	**58**
LS	35	0	1	0	**36**
Total	**344**	**14**	**1**	**14**	**359**

RU: Regular users
PS (VS): Partial sneakers (vehicles stopped)
PS (VR): Partial sneakers (vehicles running)
S: Sneakers
LS: Late starters

Jaywalkers from west side of the crosswalk = 10 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 359 + 10 + 7 = 376 peds in 30 min
Vehicular Volume (VV) = 2344 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{189}{376} = 50.3\%$$

Total pedestrian volume in the crosswalk area = 376 * 2 = 752 peds / hr
Compliance to location only = 91.49% Violation of flashing red signal = 10.03%
Compliance to signal only = 54.60%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/25/98, Wednesday, High 40 F, warm and sunny **Time:** 2:36p

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	69	0	0	15	**69**
PS (VR)	21	0	0	0	**21**
S	24	2	0	8	**26**
LS	16	2	0	0	**18**
Total	**130**	**4**	**0**	**23**	**134**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 9 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 134 + 9 + 1 = 144 peds in 30 min
Vehicular Volume (VV) = 2430 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{69}{144} = 47.9\%$$

Total pedestrian volume in the crosswalk area = 144 * 2 = 288 peds / hr
Compliance to location only = 90.28% Violation of flashing red signal = 13.43%
Compliance to signal only = 51.49%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	16	1	1	18

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 18 + 0 + 6 = 24 peds in 30 min
Vehicular Volume (VV) = 2430 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{16}{24} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 24 * 2 = 48 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/25/98, Wednesday, High 40 F, warm and sunny **Time:** 2:36p

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	53	0	2	5	**55**
PS (VR)	30	0	1	4	**31**
S	17	0	1	2	**18**
LS	6	1	0	1	**7**
Total	**106**	**1**	**4**	**12**	**111**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 111+ 6 + 2 = 119 peds in 30 min
Vehicular Volume (VV) = 2346 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{53}{119} = 44.5\%$$

Total pedestrian volume in the crosswalk area = 119 * 2 = 238 peds / hr
Compliance to location only = 89.08% Violation of flashing red signal = 6.31%
Compliance to signal only = 49.55%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	23	2	2	27

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 27 + 6 + 2 = 35 peds in 30 min
Vehicular Volume (VV) = 2356 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{23}{35} = 65.7\%$$

Total pedestrian volume in the crosswalk area = 35 * 2 = 70 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/25/98, Wednesday, High 40 F, warm and sunny **Time:** 2:36p

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	32	3	4	39

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 8 peds in 30 min
Total pedestrians in the crosswalk area = 39 + 1 + 8 = 48 peds in 30 min
Vehicular Volume (VV) = 2408 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{32}{48} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 48 * 2 = 96 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	117	17	2	8	136
PS (VR)	18	2	1	2	21
S	57	8	2	5	67
LS	20	4	0	1	24
Total	212	31	5	16	248

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 12 peds in 30 min
Jaywalkers from east side of the crosswalk = 11 peds in 30 min
Total pedestrians in the crosswalk area = 248 + 12 + 11 = 271 peds in 30 min
Vehicular Volume (VV) = 2537 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{117}{271} = 43.2\%$$

Total pedestrian volume in the crosswalk area = 271 * 2 = 542 peds / hr
Compliance to location only = 78.23% Violation of flashing red signal = 9.68%
Compliance to signal only = 54.84%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/19/98, Thursday, Mid 30 F, cold, cloudy **Time:** 2:33p

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	50	2	1	4	**53**
PS (VR)	15	0	0	1	**15**
S	19	6	0	4	**25**
LS	14	0	0	2	**14**
Total	**98**	**8**	**1**	**11**	**107**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 107 + 6 + 1 = 114 peds in 30 min
Vehicular Volume (VV) = 2488 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{50}{114} = 43.9\%$$

Total pedestrian volume in the crosswalk area = 114 * 2 = 228 peds / hr
Compliance to location only = 85.96% Violation of flashing red signal = 13.08%
Compliance to signal only = 49.53%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	45	5	1	51

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 8 peds in 30 min
Total pedestrians in the crosswalk area = 51 + 1 + 8 = 60 peds in 30 min
Vehicular Volume (VV) = 2484 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{45}{60} = 75.0\%$$

Total pedestrian volume in the crosswalk area = 60 * 2 = 120 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/19/98, Thursday, Mid 30 F, cold, cloudy **Time:** 2:33p

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	22	0	0	4	**22**
PS (VR)	8	1	0	1	**9**
S	7	0	0	2	**7**
LS	7	0	0	0	**7**
Total	**44**	**1**	**0**	**7**	**45**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 10 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 45 + 10 + 1 = 56 peds in 30 min
Vehicular Volume (VV) = 2346 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{22}{56} = 39.3\%$$

Total pedestrian volume in the crosswalk area = 56 * 2 = 112 peds / hr
Compliance to location only = 78.57% Violation of flashing red signal = 15.56%
Compliance to signal only = 48.89%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	15	1	0	16

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 16 + 1 + 3 = 20 peds in 30 min
Vehicular Volume (VV) = 2185 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{15}{20} = 75.0\%$$

Total pedestrian volume in the crosswalk area = 20 * 2 = 40 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 2/19/98, Thursday, Mid 30 F, cold, cloudy **Time:** 2:33p

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	35	5	0	40

Jaywalkers from west side of the crosswalk = 6 peds in 30 min

Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 40 + 6 + 7 = 53 peds in 30 min
Vehicular Volume (VV) = 2425 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{35}{53} = 66.0\%$$

Total pedestrian volume in the crosswalk area = 53 * 2 = 106 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	70	1	1	6	**72**
PS (VR)	18	0	1	0	**19**
S	23	4	1	2	**28**
LS	15	2	0	2	**17**
Total	**126**	**7**	**3**	**10**	**136**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 4 peds in 30 min
Jaywalkers from east side of the crosswalk = 13 peds in 30 min
Total pedestrians in the crosswalk area = 136 + 4 + 13 = 153 peds in 30 min
Vehicular Volume (VV) = 2533 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{70}{153} = 45.8\%$$

Total pedestrian volume in the crosswalk area = 153 * 2 = 306 peds / hr
Compliance to location only = 82.35% Violation of flashing red signal = 12.50%
Compliance to signal only = 52.94%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/27/98, Wednesday, Mid 80 F, sunny **Time:** 10:36a

1- Abbott St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	14	1	0	1	**15**
PS (VR)	5	1	0	0	**6**
S	8	0	3	3	**11**
LS	2	0	0	1	**2**
Total	**29**	**2**	**3**	**5**	**34**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 34 + 1 + 2 = 37 peds in 30 min
Vehicular Volume (VV) = 1516 veh/hr L_{CIA} = 38.40 m (125.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{14}{37} = 37.8\%$$

Total pedestrian volume in the crosswalk area = 37 * 2 = 74 peds / hr
Compliance to location only = 78.38% Violation of flashing red signal = 5.88%
Compliance to signal only = 44.12%

2- Midblock Crosswalk w/ shelter (in front of the MSU Student Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	9	0	2	11

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 11 + 1 + 2 = 14 peds in 30 min
Vehicular Volume (VV) = 1600 veh/hr L_{CIA} = 85.50 m (280.51 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{9}{14} = 64.3\%$$

Total pedestrian volume in the crosswalk area = 14 * 2 = 28 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/27/98, Wednesday, Mid 80 F, sunny **Time:** 10:36a

3- M.A.C. Ave. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	6	0	0	0	**6**
PS (VR)	0	0	0	0	**0**
S	5	1	0	2	**6**
LS	1	0	0	3	**1**
Total	**12**	**1**	**0**	**5**	**13**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 13 + 3 + 0 = 16 peds in 30 min
Vehicular Volume (VV) = 1652 veh/hr L_{CIA} = 97.25 m (319.06 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{6}{16} = 37.5\%$$

Total pedestrian volume in the crosswalk area = 16 * 2 = 32 peds / hr
Compliance to location only = 75.00% Violation of flashing red signal = 7.69%
Compliance to signal only = 46.15%

4- Midblock Crosswalk w/o shelter (in front of Jacobson's)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	16	4	0	20

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 20 + 2 + 2 = 24 peds in 30 min
Vehicular Volume (VV) = 1939 veh/hr L_{CIA} = 71.95 m (236.06 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{16}{24} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 24 * 2 = 48 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 5/27/98, Wednesday, Mid 80 F, sunny **Time:** 10:36a

5- Charles St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	72	4	0	76

Jaywalkers from west side of the crosswalk = 10 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 76 + 10 + 7 = 93 peds in 30 min
Vehicular Volume (VV) = 2148 veh/hr L_{CIA} = 97.85 m (321.03 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{72}{93} = 77.4\%$$

Total pedestrian volume in the crosswalk area = 93 * 2 = 186 peds / hr

6- Division St. Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	45	0	0	7	**45**
PS (VR)	14	0	0	2	**14**
S	21	1	0	4	**22**
LS	11	0	0	0	**11**
Total	**91**	**1**	**0**	**13**	**92**

RU: Regular users
PS (VS): Partial sneakers (vehicles stopped)
PS (VR): Partial sneakers (vehicles running)
S: Sneakers
LS: Late starters

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 92 + 5 + 5 = 102 peds in 30 min
Vehicular Volume (VV) = 2061 veh/hr L_{CIA} = 96.00 m (314.96 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{45}{102} = 44.1\%$$

Total pedestrian volume in the crosswalk area = 102 * 2 = 204 peds / hr
Compliance to location only = 89.22% Violation of flashing red signal = 11.96%
Compliance to signal only = 48.91%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 4/24/98, Friday, High 60 F, sunny **Time:** 3:26p

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union & Berkeley Hall)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	80	7	1	88

Jaywalkers from west side of the crosswalk = 7 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 88 + 7 + 3 = 98 peds in 30 min
Vehicular Volume (VV) = 2506 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{80}{98} = 81.6\%$$

Total pedestrian volume in the crosswalk area = 98 * 2 = 196 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	23	0	10	33

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 33 + 3 + 0 = 36 peds in 30 min
Vehicular Volume (VV) = 2464 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{23}{36} = 63.9\%$$

Total pedestrian volume in the crosswalk area = 36 * 2 = 72 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 4/24/98, Friday, High 60 F, sunny **Time:** 3:26p

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	15	0	3	18

Jaywalkers from west side of the crosswalk = 3 peds in 30 min

Jaywalkers from east side of the crosswalk = 2 peds in 30 min

Total pedestrians in the crosswalk area = 18 + 3 + 2 = 23 peds in 30 min

Vehicular Volume (VV) = 2574 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{15}{23} = 65.2\%$$

Total pedestrian volume in the crosswalk area = 23 * 2 = 46 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey St, in front of Good Time Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	39	0	0	39

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 39 + 3 + 1 = 43 peds in 30 min
Vehicular Volume (VV) = 2799 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{39}{43} = 90.7\%$$

Total pedestrian volume in the crosswalk area = 43 * 2 = 86 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 4/24/98, Friday, High 60 F, sunny **Time:** 3:26p
11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	8	2	0	2	**10**
PS (VR)	0	0	0	0	**0**
S	5	0	1	1	**6**
LS	1	2	0	1	**3**
Total	**14**	**4**	**1**	**4**	**19**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)
Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 19 + 1 + 0 = 20 peds in 30 min
Vehicular Volume (VV) = 2812 veh/hr L_{CIA} = 35.35 m (115.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{8}{20} = 40.0\%$$

Total pedestrian volume in the crosswalk area = 20 * 2 = 40 peds / hr
Compliance to location only = 70.00% Violation of flashing red signal = 15.79%
Compliance to signal only = 52.63%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	10	0	0	5	**10**
PS (VR)	0	0	0	0	**0**
S	3	0	0	0	**3**
LS	2	0	0	0	**2**
Total	**15**	**0**	**0**	**5**	**15**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)
Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 15 + 0 + 6 = 21 peds in 30 min
Vehicular Volume (VV) = 2708 veh/hr L_{CIA} = 50.90 m (166.99 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{10}{21} = 47.6\%$$

Total pedestrian volume in the crosswalk area = 16 * 2 = 32 peds / hr
Compliance to location only = 71.43% Violation of flashing red signal = 13.33%
Compliance to signal only = 66.67%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)

Date: 4/24/98, Friday, High 60 F, sunny **Time:** 3:26p

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	21	0	0	21

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 21 + 6 + 1 = 28 peds in 30 min
Vehicular Volume (VV) = 2813 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{21}{28} = 75.0\%$$

Total pedestrian volume in the crosswalk area = 28 * 2 = 56 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrian count- 30 min	24

Jaywalkers in the Bogue St area = 24 peds in 30 min

Pedestrian compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = 24 * 2 = 48 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 4/23/98, Thursday, Low 70 F, sunny **Time:** 11:02a

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	59	13	1	73

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 73 + 5 + 7= 85 peds in 30 min
Vehicular Volume (VV) = 1706 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{59}{85} = 69.4\%$$

Total pedestrian volume in the crosswalk area = 85 * 2 = 170 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	42	0	27	69

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 69 + 3 + 0 = 72 peds in 30 min
Vehicular Volume (VV) = 1860 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{42}{72} = 58.3\%$$

Total pedestrian volume in the crosswalk area = 72 * 2 = 144 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)
Date: 4/23/98, Thursday, Low 70 F, sunny **Time:** 11:02a

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	47	0	18	65

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 4 peds in 30 min
Total pedestrians in the crosswalk area = 65 + 0 + 4 = 69 peds in 30 min
Vehicular Volume (VV) = 1880 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{47}{69} = 68.1\%$$

Total pedestrian volume in the crosswalk area = 69 * 2 = 138 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey Street)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	74	7	1	82

Jaywalkers from west side of the crosswalk = 10 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 82 + 10 + 3 = 95 peds in 30 min
Vehicular Volume (VV) = 2339 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{74}{95} = 77.9\%$$

Total pedestrian volume in the crosswalk area = 95 * 2 = 190 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)

Date: 4/23/98, Thursday, Low 70 F, sunny **Time:** 11:02a

11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	9	0	0	4	**9**
PS (VR)	4	0	0	0	**4**
S	6	0	0	5	**6**
LS	5	0	0	2	**5**
Total	**24**	**0**	**0**	**11**	**24**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 1 peds in 30 min

Jaywalkers from east side of the crosswalk = 0 peds in 30 min

Total pedestrians in the crosswalk area = 24 + 1 + 0 = 25 peds in 30 min

Vehicular Volume (VV) = 2270 veh/hr L_{CIA} = 35.35 m (115.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{9}{25} = 36.0\%$$

Total pedestrian volume in the crosswalk area = 25 * 2 = 50 peds / hr

Compliance to location only = 96.00% Violation of flashing red signal = 20.83%

Compliance to signal only = 37.50%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	14	0	0	4	**14**
PS (VR)	7	0	0	1	**7**
S	5	2	1	1	**8**
LS	1	0	0	0	**1**
Total	**27**	**2**	**1**	**6**	**30**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min

Jaywalkers from east side of the crosswalk = 9 peds in 30 min

Total pedestrians in the crosswalk area = 30 + 0 + 9 = 39 peds in 30 min

Vehicular Volume (VV) = 2468 veh/hr L_{CIA} = 50.90 m (166.99 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{14}{39} = 35.9\%$$

Total pedestrian volume in the crosswalk area = 39 * 2 = 78 peds / hr

Compliance to location only = 69.23% Violation of flashing red signal = 3.33%

Compliance to signal only = 46.67%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (ABBOTT - BOGUE STS)

Date: 4/23/98, Thursday, Low 70 F, sunny **Time:** 11:02a

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	64	10	1	75

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 75 + 5 + 2 = 82 peds in 30 min
Vehicular Volume (VV) = 2760 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{64}{82} = 78.0\%$$

Total pedestrian volume in the crosswalk area = 78 * 2 = 156 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrian counts- 30 min	20

Jaywalkers in the Bogue St area = 20 peds in 30 min

Crossing compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = 20 * 2 = 40 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/28/98, Tuesday, Low 60 F, sunny **Time:** 10:58a

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	88	8	3	99

Jaywalkers from west side of the crosswalk = 14 peds in 30 min

Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 99 + 14 + 7= 120 peds in 30 min
Vehicular Volume (VV) = 1922 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{88}{120} = 73.3\%$$

Total pedestrian volume in the crosswalk area = 120 * 2 = 240 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	15	0	3	18

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 4 peds in 30 min
Total pedestrians in the crosswalk area = 18 + 2 + 4 = 24 peds in 30 min
Vehicular Volume (VV) = 1804 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{15}{24} = 62.5\%$$

Total pedestrian volume in the crosswalk area = 24 * 2 = 48 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/28/98, Tuesday, Low 60 F, sunny **Time:** 10:58a

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	24	0	10	34

Jaywalkers from west side of the crosswalk = 3 peds in 30 min

Jaywalkers from east side of the crosswalk = 4 peds in 30 min

Total pedestrians in the crosswalk area = 34 + 3 + 4 = 41 peds in 30 min
Vehicular Volume (VV) = 1942 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{24}{41} = 58.5\%$$

Total pedestrian volume in the crosswalk area = 41 * 2 = 82 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey St, in front of Good Time Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	40	8	0	48

Jaywalkers from west side of the crosswalk = 10 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 48 + 10 + 1 = 59 peds in 30 min
Vehicular Volume (VV) = 2156 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{40}{59} = 67.8\%$$

Total pedestrian volume in the crosswalk area = 59 * 2 = 118 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/28/98, Tuesday, Low 60 F, sunny **Time:** 10:58a

11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	19	1	0	7	**20**
PS (VR)	3	0	0	1	**3**
S	5	0	0	5	**5**
LS	5	1	0	0	**6**
Total	**32**	**2**	**0**	**13**	**34**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 1 peds in 30 min

Jaywalkers from east side of the crosswalk = 0 peds in 30 min

Total pedestrians in the crosswalk area = 34 + 1 + 0 = 35 peds in 30 min

Vehicular Volume (VV) = 2198 veh/hr L_{CIA} = 35.35 m (115.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{19}{35} = 54.3\%$$

Total pedestrian volume in the crosswalk area = 35 * 2 = 70 peds / hr

Compliance to location only = 91.43% Violation of flashing red signal = 17.65%

Compliance to signal only = 58.82%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	18	0	0	2	**18**
PS (VR)	1	0	0	0	**1**
S	1	0	0	1	**1**
LS	6	0	0	0	**6**
Total	**26**	**0**	**0**	**3**	**26**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min

Jaywalkers from east side of the crosswalk = 12 peds in 30 min

Total pedestrians in the crosswalk area = 26 + 0 + 12 = 38 peds in 30 min

Vehicular Volume (VV) = 2370 veh/hr L_{CIA} = 50.90 m (166.99 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{18}{38} = 47.4\%$$

Total pedestrian volume in the crosswalk area = 38 * 2 = 76 peds / hr

Compliance to location only = 68.42% Violation of flashing red signal = 23.08%

Compliance to signal only = 69.23%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/28/98, Tuesday, Low 60 F, sunny **Time:** 10:58a

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrians	43	10	3	56

Jaywalkers from west side of the crosswalk = 7 peds in 30 min
Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 56 + 7 + 5 = 68 peds in 30 min
Vehicular Volume (VV) = 2556 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{43}{68} = 63.2\%$$

Total pedestrian volume in the crosswalk area = 68 * 2 = 136 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrians	18

Jaywalkers in the Bogue St area = 18 peds in 30 min

Crossing compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = 18 * 2 = 36 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/30/98, Thursday, High 60 F, cloudy **Time:** 10:59a

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	84	9	3	96

Jaywalkers from west side of the crosswalk = 15peds in 30 min
Jaywalkers from east side of the crosswalk = 9 peds in 30 min
Total pedestrians in the crosswalk area = 96 + 15 + 9= 120 peds in 30 min
Vehicular Volume (VV) = 1768 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{84}{120} = 70.0\%$$

Total pedestrian volume in the crosswalk area = 120 * 2 = 240 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	21	0	3	24

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 10 peds in 30 min
Total pedestrians in the crosswalk area = 24 + 0 + 10 = 34 peds in 30 min
Vehicular Volume (VV) = 1992 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{21}{34} = 61.8\%$$

Total pedestrian volume in the crosswalk area = 34 * 2 = 68 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/30/98, Thursday, High 60 F, cloudy **Time:** 10:59a

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	21	0	5	26

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 26 + 6 + 1 = 33 peds in 30 min
Vehicular Volume (VV) = 1912 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{21}{33} = 63.6\%$$

Total pedestrian volume in the crosswalk area = 33 * 2 = 66 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey St, in front of Good Time Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	70	2	1	73

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 73 + 3 + 1 = 77 peds in 30 min
Vehicular Volume (VV) = 2372 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{70}{77} = 90.9\%$$

Total pedestrian volume in the crosswalk area = 77 * 2 = 154 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/30/98, Thursday, High 60 F, cloudy **Time:** 10:59a

11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	17	0	0	7	**17**
PS (VR)	4	0	0	3	**4**
S	5	0	1	5	**6**
LS	1	0	0	1	**1**
Total	**27**	**0**	**1**	**16**	**28**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min

Jaywalkers from east side of the crosswalk = 0 peds in 30 min

Total pedestrians in the crosswalk area = 28 + 0 + 0 = 28 peds in 30 min

Vehicular Volume (VV) = 2358 veh/hr L_{CIA} = 35.35 m (115.98 ft)

Overall compliance rate = *No of RUs + no PS(VS)s on-crosswalk* / *Total peds in the crosswalk area* = 17 / 28 = 60.7%

Total pedestrian volume in the crosswalk area = 28 * 2 = 56 peds / hr

Compliance to location only = 96.43% Violation of flashing red signal = 3.57%

Compliance to signal only = 60.71%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	15	0	0	2	**15**
PS (VR)	4	0	0	0	**4**
S	1	0	0	0	**1**
LS	2	0	0	0	**2**
Total	**22**	**0**	**0**	**2**	**22**

RU: Regular users S: Sneakers

PS (VS): Partial sneakers (vehicles stopped) LS: Late starters

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min

Jaywalkers from east side of the crosswalk = 8 peds in 30 min

Total pedestrians in the crosswalk area = 22 + 0 + 8 = 30 peds in 30 min

Vehicular Volume (VV) = 2552 veh/hr L_{CIA} = 50.90 m (166.99 ft)

Overall compliance rate = *No of RUs + no PS(VS)s on-crosswalk* / *Total peds in the crosswalk area* = 15 / 30 = 50.0%

Total pedestrian volume in the crosswalk area = 30 * 2 = 60 peds / hr

Compliance to location only = 73.33% Violation of flashing red signal = 9.09%

Compliance to signal only = 68.18%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/30/98, Thursday, High 60 F, cloudy **Time:** 10:59a

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	39	6	1	46

Jaywalkers from west side of the crosswalk = 5 peds in 30 min
Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 46 + 5 + 5 = 56 peds in 30 min
Vehicular Volume (VV) = 2928 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{39}{56} = 69.6\%$$

Total pedestrian volume in the crosswalk area = 56 * 2 = 112 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrian count- 30 min	17

Jaywalkers in the Bogue St area = 17 peds in 30 min

Crossing compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = 17 * 2 = 34 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/20/98, Monday, Low 60 F, partly cloudy **Time:** 3:26p

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	95	13	1	109

Jaywalkers from west side of the crosswalk = 7 peds in 30 min

Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 109 + 7 + 5= 121 peds in 30 min
Vehicular Volume (VV) = 2304 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{95}{121} = 78.5\%$$

Total pedestrian volume in the crosswalk area = 121 * 2 = 242 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	29	0	9	38

Jaywalkers from west side of the crosswalk = 1 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 38 + 1 + 3 = 42 peds in 30 min
Vehicular Volume (VV) = 2444 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{29}{42} = 69.0\%$$

Total pedestrian volume in the crosswalk area = 42 * 2 = 84 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/20/98, Monday, Low 60 F, partly cloudy **Time:** 3:26p

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	45	0	13	58

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 3 peds in 30 min
Total pedestrians in the crosswalk area = 58 + 6 + 3 = 67 peds in 30 min
Vehicular Volume (VV) = 2444 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{45}{67} = 67.2\%$$

Total pedestrian volume in the crosswalk area = 67 * 2 = 134 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey St, in front of Good Time Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	46	3	0	49

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 49 + 3 + 0 = 52 peds in 30 min
Vehicular Volume (VV) = 2436 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{46}{52} = 88.5\%$$

Total pedestrian volume in the crosswalk area = 52 * 2 = 104 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/20/98, Monday, Low 60 F, partly cloudy **Time:** 3:26p

11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	13	0	0	4	**13**
PS (VR)	8	0	0	4	**8**
S	4	0	0	4	**4**
LS	1	0	0	0	**1**
Total	**26**	**0**	**0**	**12**	**26**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 0 peds in 30 min
Total pedestrians in the crosswalk area = 26 + 2 + 0 = 28 peds in 30 min
Vehicular Volume (VV) = 2444 veh/hr L_{CIA} = 35.35 m (115.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{13}{28} = 46.4\%$$

Total pedestrian volume in the crosswalk area = 28 * 2 = 56 peds / hr
Compliance to location only = 92.86% Violation of flashing red signal = 3.85%
Compliance to signal only = 50.00%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	11	0	0	4	**11**
PS (VR)	12	0	0	4	**12**
S	6	0	0	0	**6**
LS	3	0	0	1	**3**
Total	**32**	**0**	**0**	**9**	**32**

RU: Regular users **S: Sneakers**
PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**
PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min
Jaywalkers from east side of the crosswalk = 4 peds in 30 min
Total pedestrians in the crosswalk area = 32 + 0 + 4 = 36 peds in 30 min
Vehicular Volume (VV) = 2568 veh/hr L_{CIA} = 50.90 m (166.99 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{11}{36} = 30.6\%$$

Total pedestrian volume in the crosswalk area = 36 * 2 = 72 peds / hr
Compliance to location only = 88.89% Violation of flashing red signal = 9.38%
Compliance to signal only = 34.4%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/20/98, Monday, Low 60 F, partly cloudy **Time:** 3:26p

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	30	6	0	36

Jaywalkers from west side of the crosswalk = 3 peds in 30 min
Jaywalkers from east side of the crosswalk = 7 peds in 30 min
Total pedestrians in the crosswalk area = 36 + 3 + 7 = 46 peds in 30 min
Vehicular Volume (VV) = 2745 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{30}{46} = 65.2\%$$

Total pedestrian volume in the crosswalk area = 46 * 2 = 92 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrian count- 30 min	28

Jaywalkers in the Bogue St area = 28 peds in 30 min

Crossing compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = 28 * 2 = 56 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/17/98, Friday, High 50 F, partly cloudy **Time:** 3:29p

7- Midblock Crosswalk w/ shelter (in front of the MSU Federal Credit Union)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	95	8	0	103

Jaywalkers from west side of the crosswalk = 9 peds in 30 min
Jaywalkers from east side of the crosswalk = 6 peds in 30 min
Total pedestrians in the crosswalk area = 103 + 9 + 6= 118 peds in 30 min
Vehicular Volume (VV) = 2790 veh/hr L_{CIA} = 59.90 m (196.52 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{95}{118} = 80.5\%$$

Total pedestrian volume in the crosswalk area = 118 * 2 = 236 peds / hr

8- 1st Non-striped Midblock Crosswalk w/o shelter (in front of SPLASH)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	28	0	7	35

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 5 peds in 30 min
Total pedestrians in the crosswalk area = 35 + 2 + 5 = 42 peds in 30 min
Vehicular Volume (VV) = 2782 veh/hr L_{CIA} = 31.70 m (104.00 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{28}{42} = 66.7\%$$

Total pedestrian volume in the crosswalk area = 42 * 2 = 84 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)
Date: 4/17/98, Friday, High 50 F, partly cloudy **Time:** 3:29p

9- 2nd Non-striped Midblock Crosswalk w/o shelter (in front of University Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	27	0	4	31

Jaywalkers from west side of the crosswalk = 6 peds in 30 min

Jaywalkers from east side of the crosswalk = 4 peds in 30 min

Total pedestrians in the crosswalk area = 31 + 6 + 4 = 41 peds in 30 min

Vehicular Volume (VV) = 2894 veh/hr L_{CIA} = 48.16 m (158.01 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{27}{41} = 65.9\%$$

Total pedestrian volume in the crosswalk area = 41 * 2 = 82 peds / hr

10- Midblock Crosswalk w/o shelter (Bailey St, in front of Good Time Pizza)

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	37	2	0	39

Jaywalkers from west side of the crosswalk = 6 peds in 30 min
Jaywalkers from east side of the crosswalk = 1 peds in 30 min
Total pedestrians in the crosswalk area = 39 + 6 + 1 = 46 peds in 30 min
Vehicular Volume (VV) = 2905 veh/hr L_{CIA} = 72.55 m (238.02 ft)

$$\text{Crossing compliance rate} = \frac{\textit{no of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{37}{46} = 80.4\%$$

Total pedestrian volume in the crosswalk area = 46 * 2 = 92 peds / hr

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/17/98, Friday, High 50 F, partly cloudy **Time:** 3:29p

11- Collingwood St. West-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	10	0	0	4	**10**
PS (VR)	1	0	0	0	**1**
S	3	0	0	2	**3**
LS	5	0	0	0	**5**
Total	**19**	**0**	**0**	**6**	**19**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 1 peds in 30 min

Jaywalkers from east side of the crosswalk = 0 peds in 30 min

Total pedestrians in the crosswalk area = 19 + 1 + 0 = 20 peds in 30 min

Vehicular Volume (VV) = 2798 veh/hr L_{CIA} = 35.35 m (115.98 ft)

$$\text{Overall compliance rate} = \frac{\textit{No of RUs + no PS(VS)s on-crosswalk}}{\textit{Total peds in the crosswalk area}} = \frac{10}{20} = 50.0\%$$

Total pedestrian volume in the crosswalk area = 20 * 2 = 40 peds / hr

Compliance to location only= 95.00% Violation of flashing red signal= 26.32%

Compliance to signal only= 52.63%

12- Collingwood St. East-Side Signalized Intersection Crosswalk

Pedestrian counts- 30 min	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Bikes	Total
RU + PS (VS)	13	0	0	3	**13**
PS (VR)	13	0	0	1	**13**
S	0	0	0	1	**0**
LS	5	0	0	1	**5**
Total	**31**	**0**	**0**	**6**	**31**

RU: Regular users **S: Sneakers**

PS (VS): Partial sneakers (vehicles stopped) **LS: Late starters**

PS (VR): Partial sneakers (vehicles running)

Jaywalkers from west side of the crosswalk = 0 peds in 30 min

Jaywalkers from east side of the crosswalk = 3 peds in 30 min

Total pedestrians in the crosswalk area = 31 + 0 + 3 = 34 peds in 30 min

Vehicular Volume (VV) = 2980 veh/hr L_{CIA} = 50.90 m (166.99 ft)

$$\text{Overall compliance rate} = \frac{\textit{no of RUs + no PS(VS)s on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{13}{34} = 38.2\%$$

Total pedestrian volume in the crosswalk area = 34 * 2 = 68 peds / hr

Compliance to location only = 91.18% Violation of flashing red signal = 16.13%

Compliance to signal only = 41.9%

GD RIVER AVE (M-43) PEDESTRIAN CROSSWALKS (DIVISION - BOGUE STS)

Date: 4/17/98, Friday, High 50 F, partly cloudy **Time:** 3:29p

13- Orchard St. Unsignalized Intersection Crosswalk

	On-crosswalk	Partial Jaywalkers	Jaywalkers around CA	Total
Pedestrian count- 30 min	10	4	0	14

Jaywalkers from west side of the crosswalk = 2 peds in 30 min
Jaywalkers from east side of the crosswalk = 2 peds in 30 min
Total pedestrians in the crosswalk area = 10 + 2 + 2 = 14 peds in 30 min

Vehicular Volume (VV) = 3203 veh/hr L_{CIA} = 101.80 m (333.99 ft)

$$\text{Pedestrian compliance} = \frac{\textit{No of Pedestrians on-crosswalk}}{\textit{total peds in the crosswalk area}} = \frac{10}{14} = 71.4\%$$

Total pedestrian volume in the crosswalk area = 14 * 2 = 28 peds / hr

14- Bogue St Intersection (no crosswalk)

	Jaywalkers
Pedestrian count- 30 min	

Jaywalkers in the Bogue St area = -- peds in 30 min

Crossing compliance = not applicable (because there was no crosswalk during data collection)

Total pedestrian volume in the intersection area = -- * 2 = -- peds / hr

APPENDIX B: Pedestrian Crossing Compliance Rates of all the Marked Midblock Crosswalks

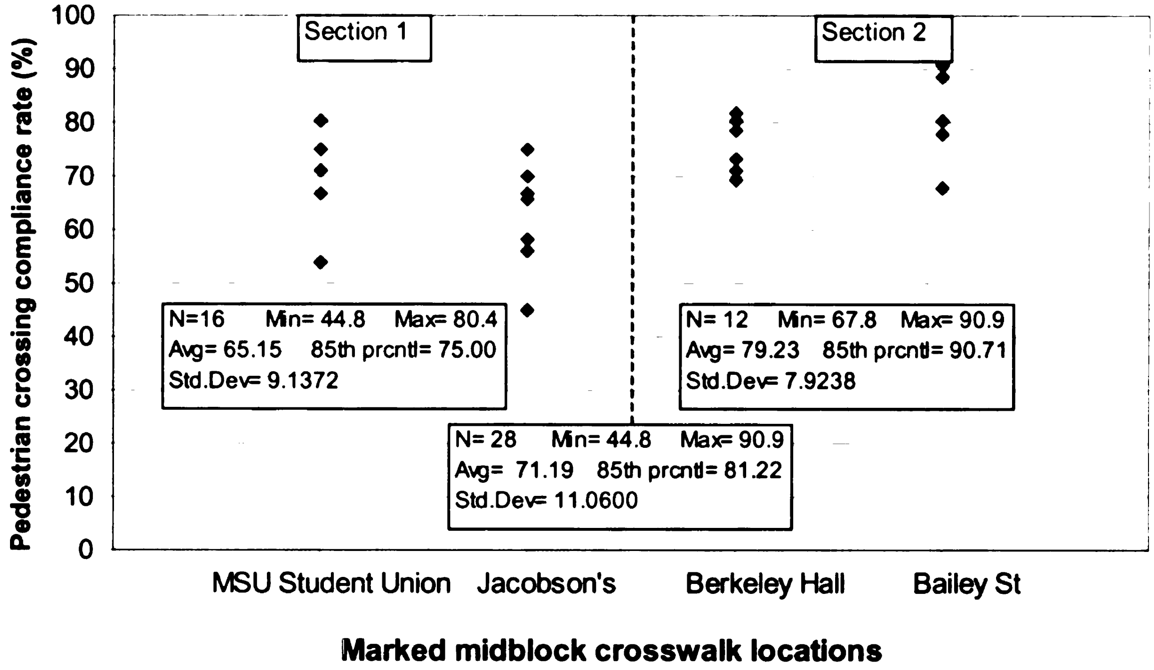

Figure B.1. Pedestrian crossing compliance rates of all the marked midblock crosswalks--all data collection sessions

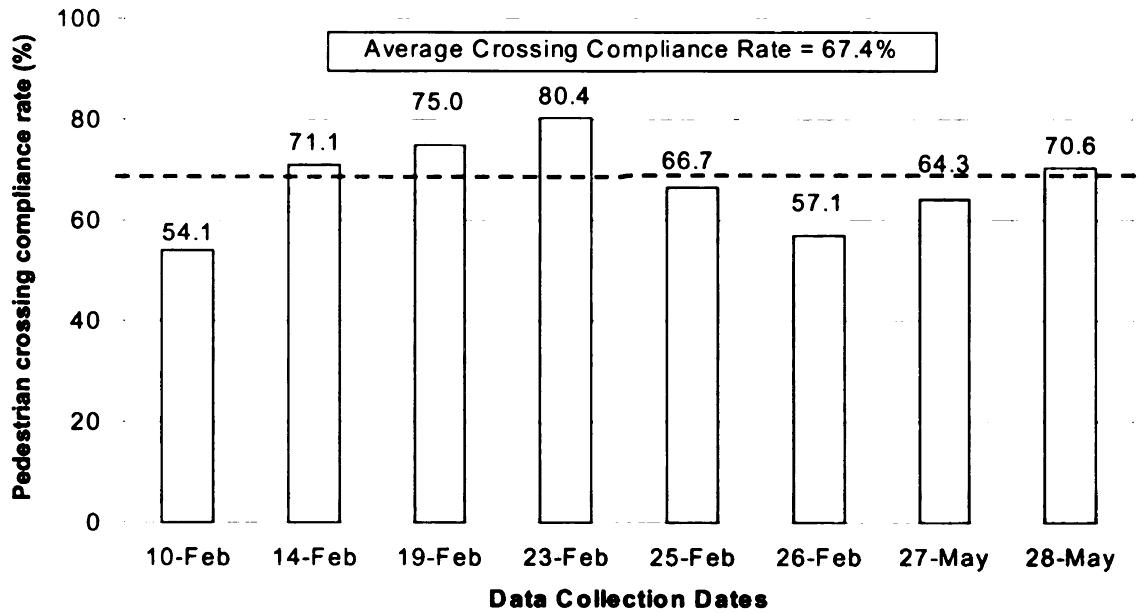

Figure B.2. Pedestrian crossing compliance rates--MSU Student Union marked midblock crosswalk

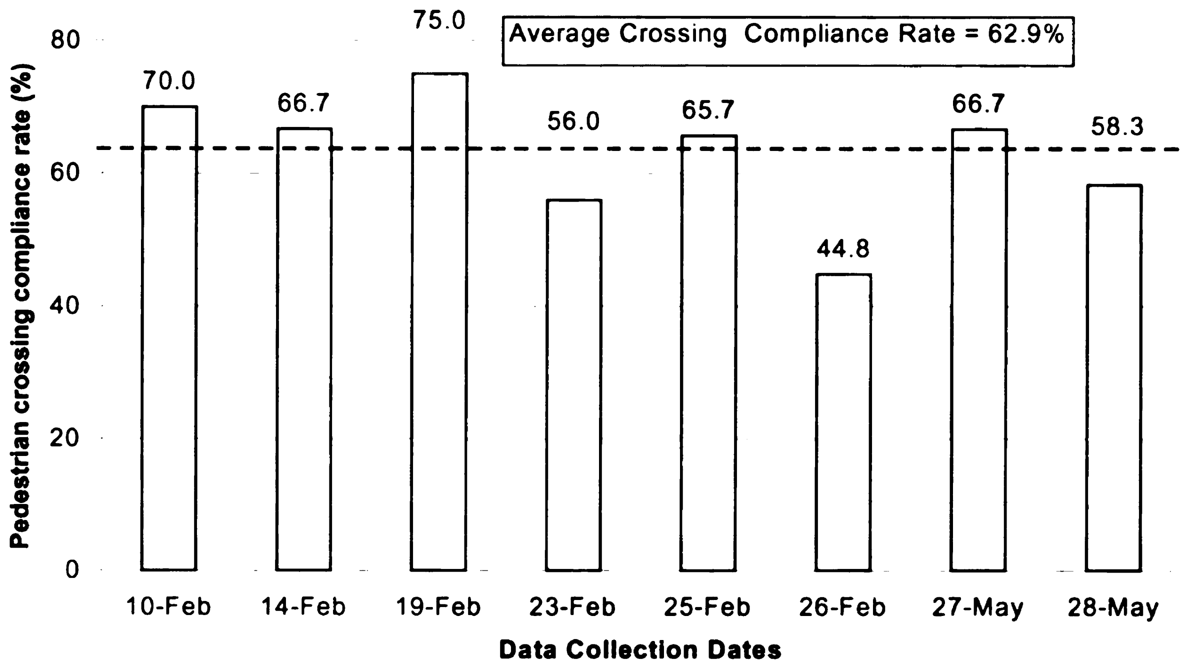

Figure B.3. Pedestrian crossing compliance rates--Jacobson's marked midblock crosswalk w/o shelter

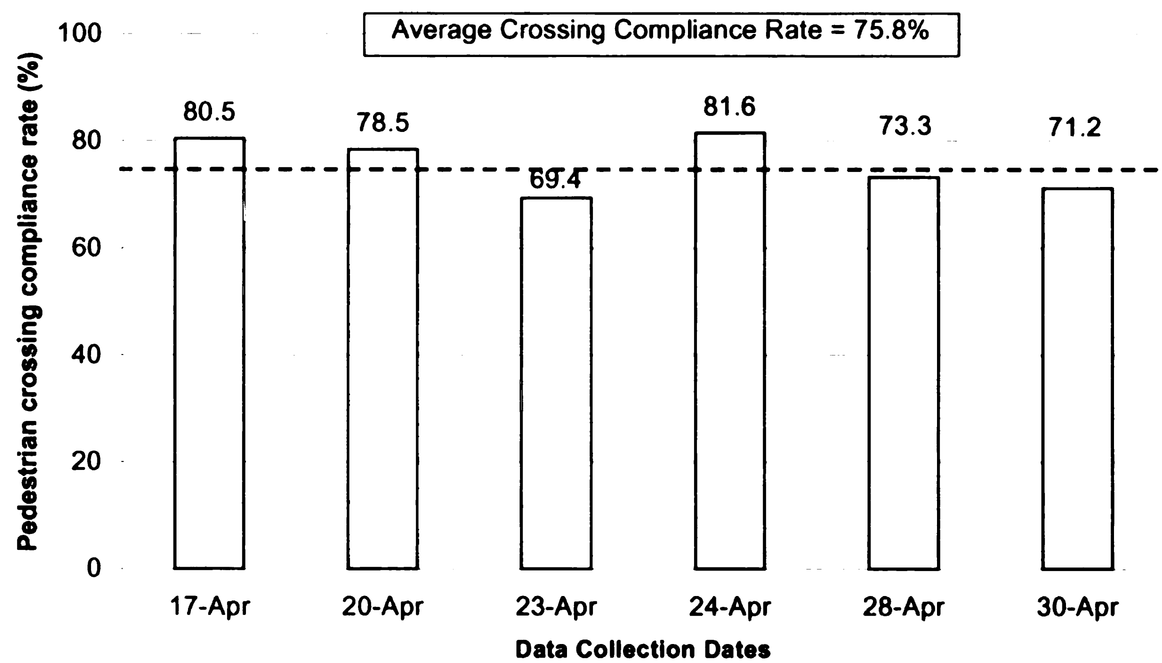

Figure B.4. Pedestrian crossing compliance rates--Berkeley Hall marked midblock crosswalk

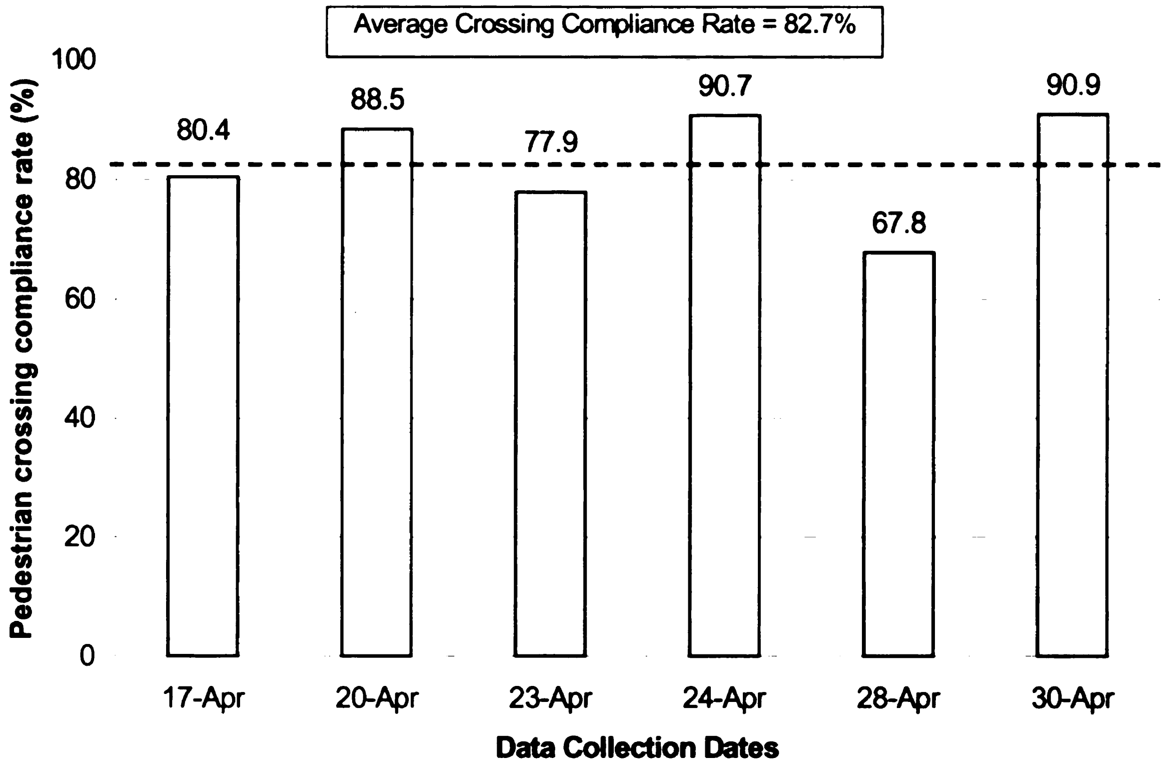

Figure B.5. Pedestrian crossing compliance rates--Bailey Street marked midblock crosswalk w/o shelter

APPENDIX C: Pedestrian Crossing Compliance Rates of all the Non-striped Midblock Crosswalks

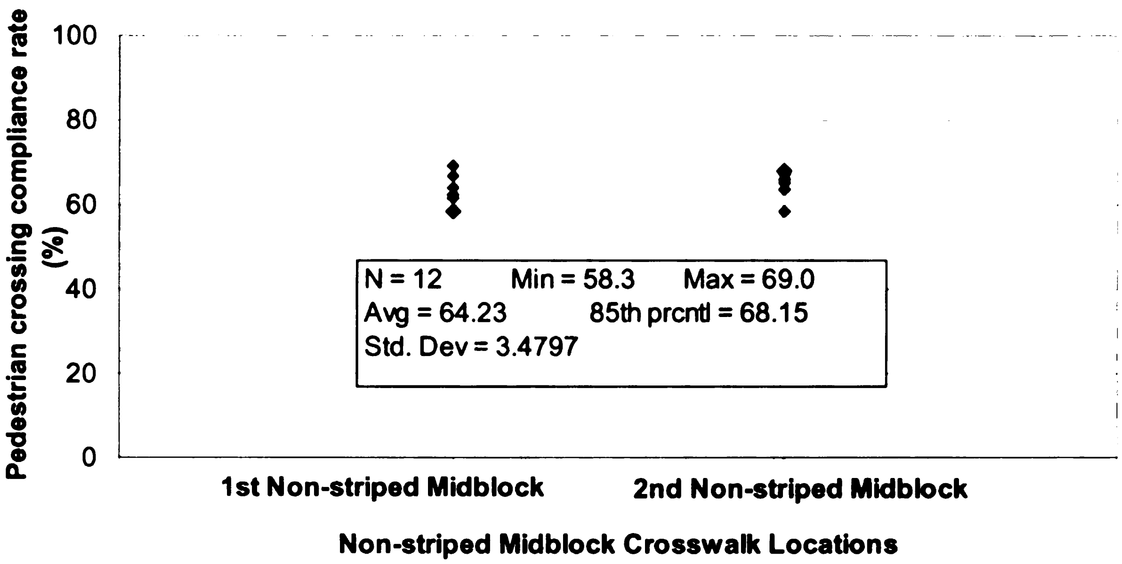

Figure C.1. Pedestrian crossing compliance rates of all the non-striped midblock crosswalks- all data collection sessions

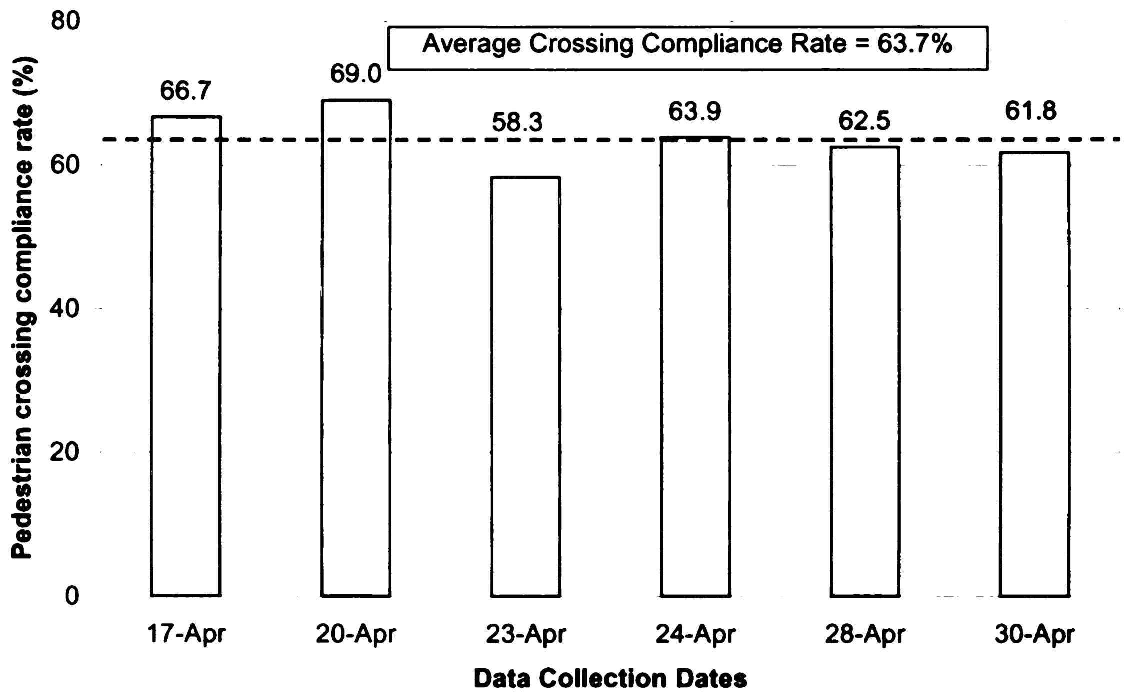

Figure C.2. Pedestrian crossing compliance rates- 1st non-striped midblock crosswalk in front of Berkeley Hall

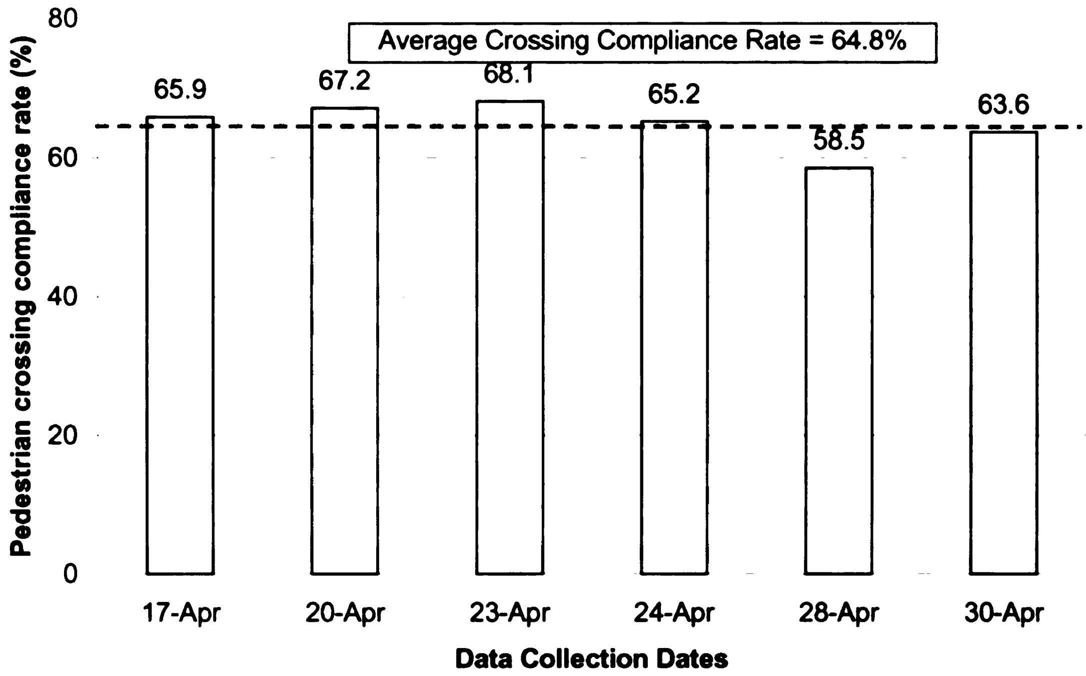

Figure C.3. Pedestrian crossing compliance rates- 2nd non-striped midblock crosswalk in front of Berkeley Hall

APPENDIX D: Pedestrian Crossing Compliance Rates of all the Unsignalized Intersection Crosswalks

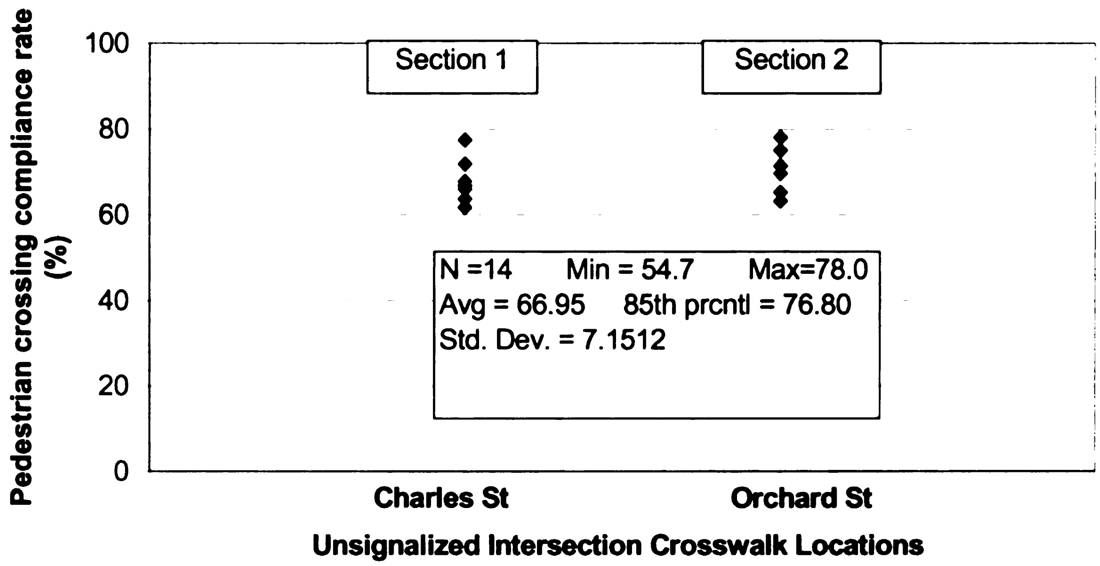

Figure D.1. Pedestrian crossing compliance rates of all the unsignalized intersection crosswalks- all data collection sessions

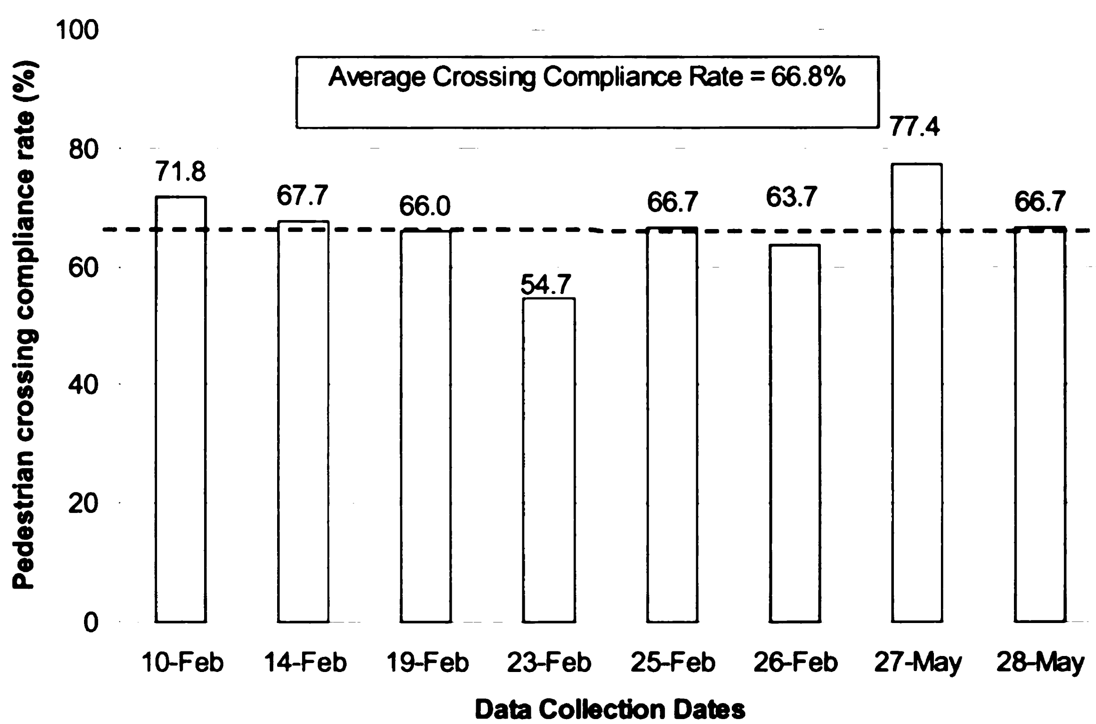

Figure D.2. Pedestrian crossing compliance rates- Charles St unsignalized intersection crosswalk

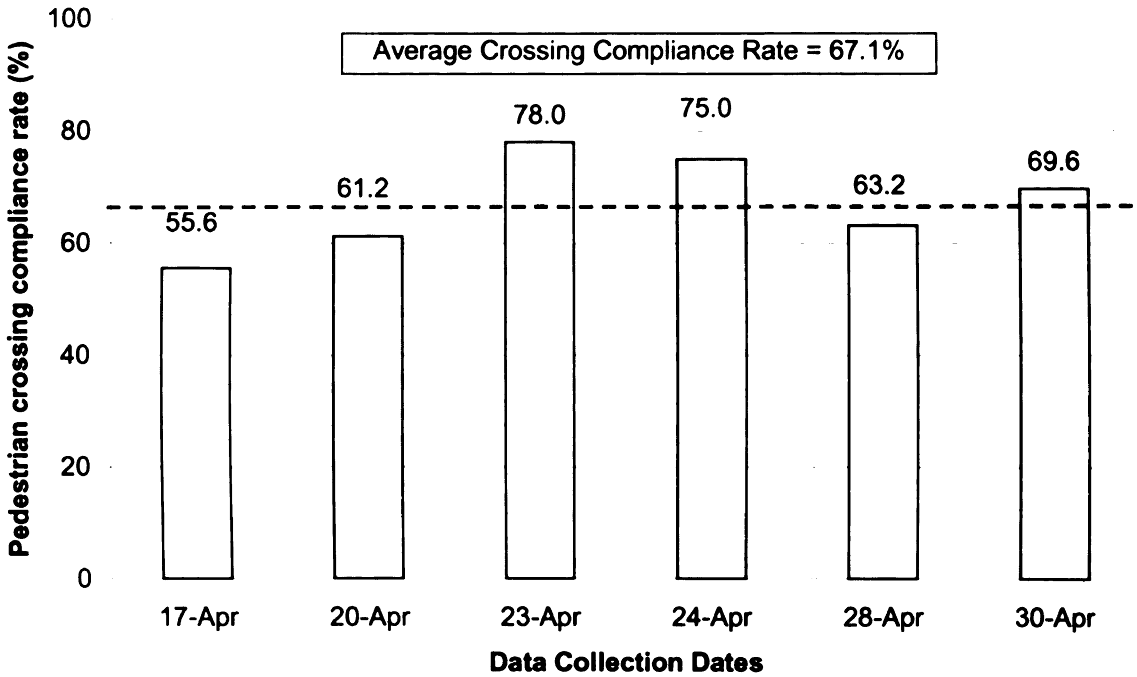

Figure D.3. Pedestrian crossing compliance rates- Orchard St unsignalized intersection crosswalk

APPENDIX E: Pedestrian Spatial Crossing Compliance Rates of all the Signalized Intersection Crosswalks

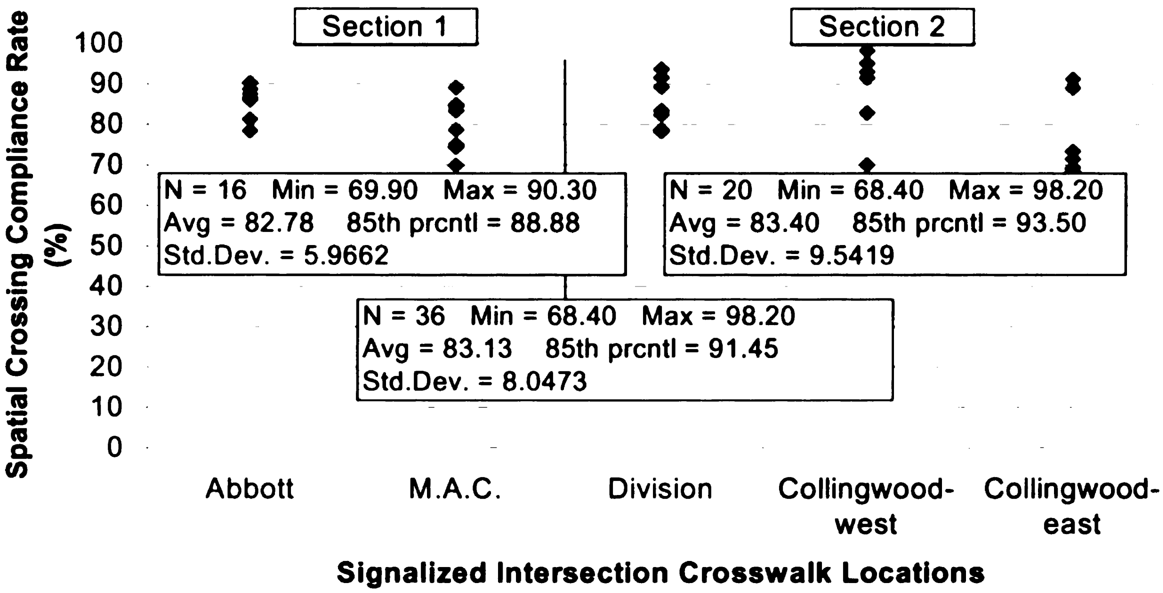

Figure E.1. Pedestrian spatial crossing compliance rates of all the signalized intersection crosswalks- all data collection sessions

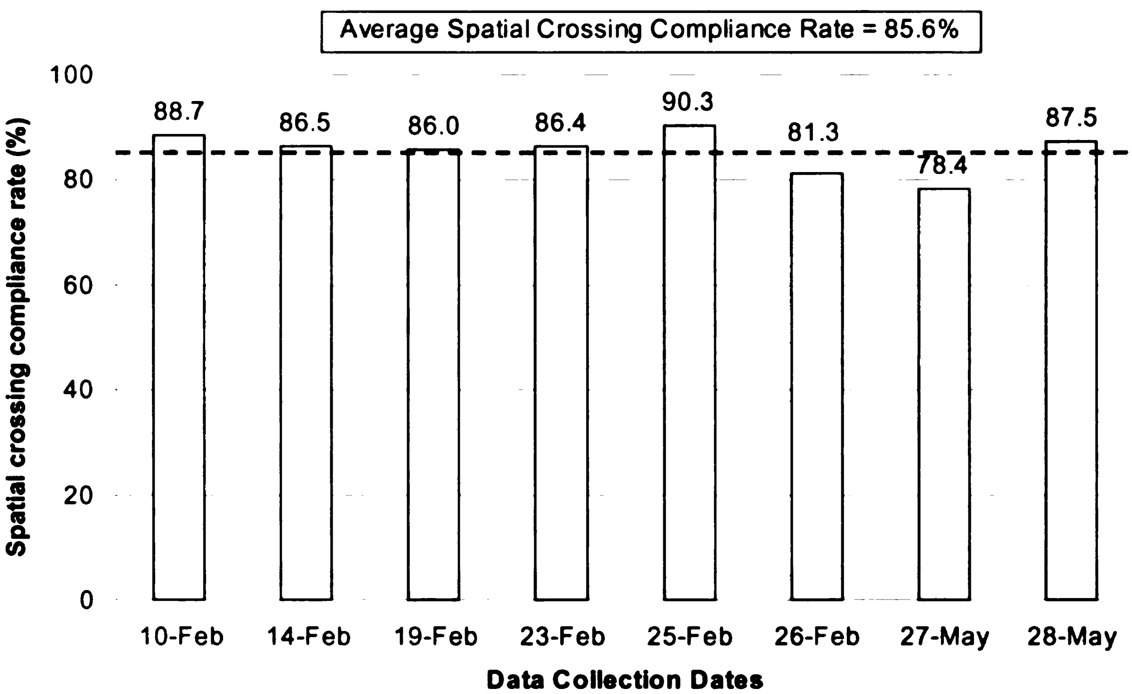

Figure E.2. Pedestrian spatial crossing compliance rates- Abbott St signalized intersection crosswalk

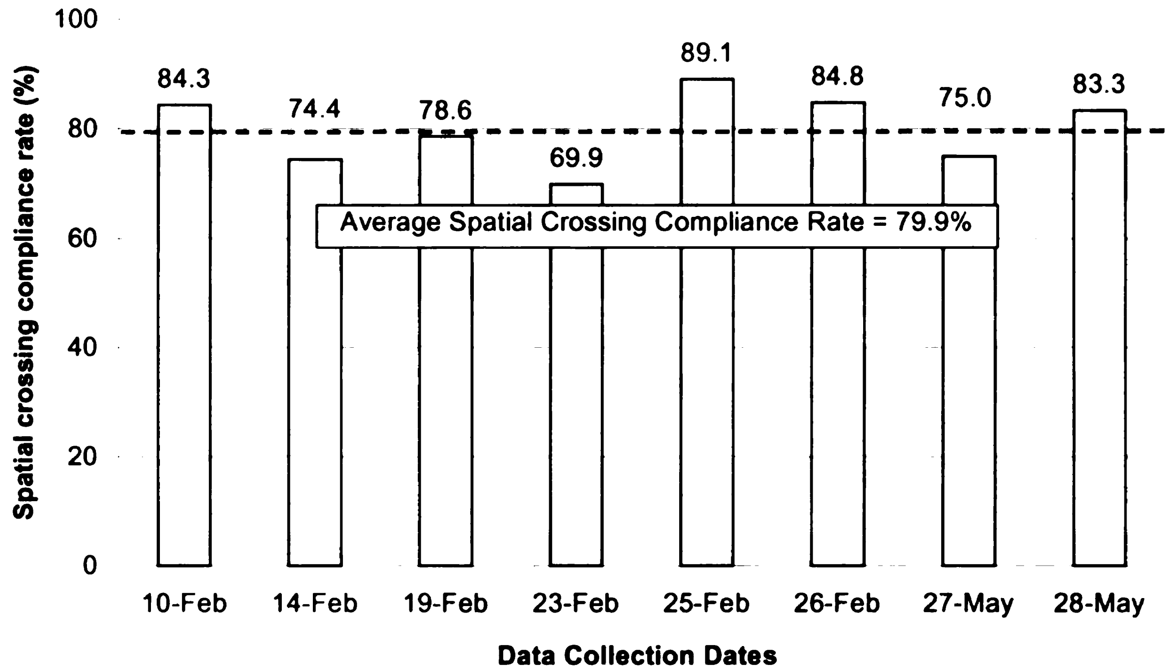

Figure E.3. Pedestrian spatial crossing compliance rates- M.A.C. Ave signalized intersection crosswalk

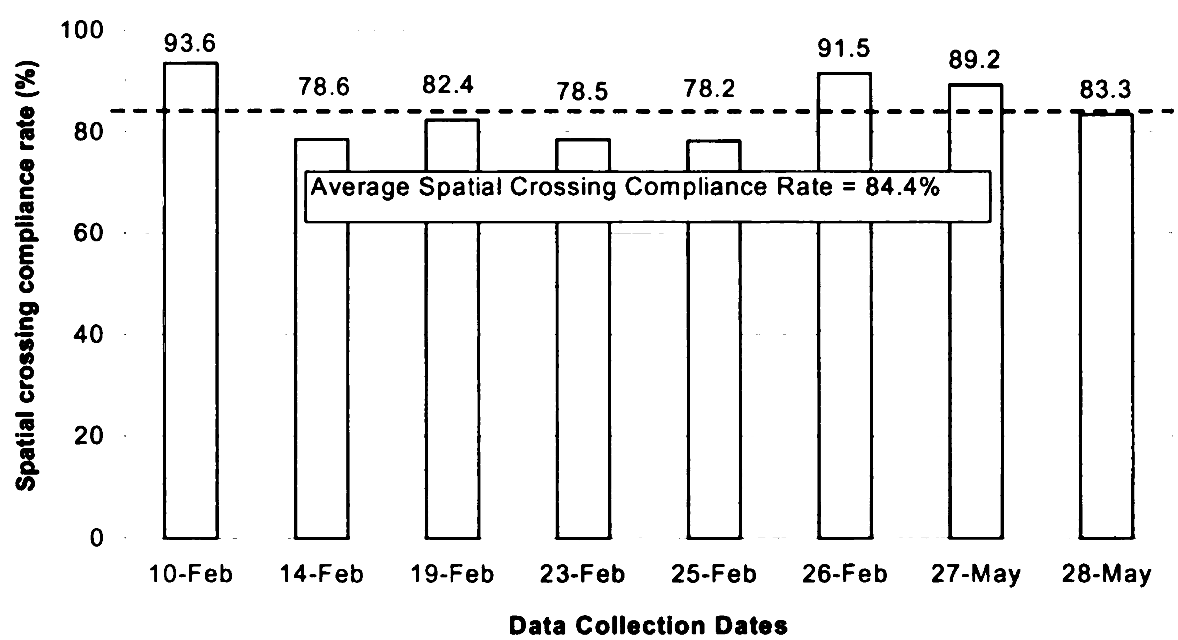

Figure E.4. Pedestrian spatial crossing compliance rates- Division St signalized intersection crosswalk

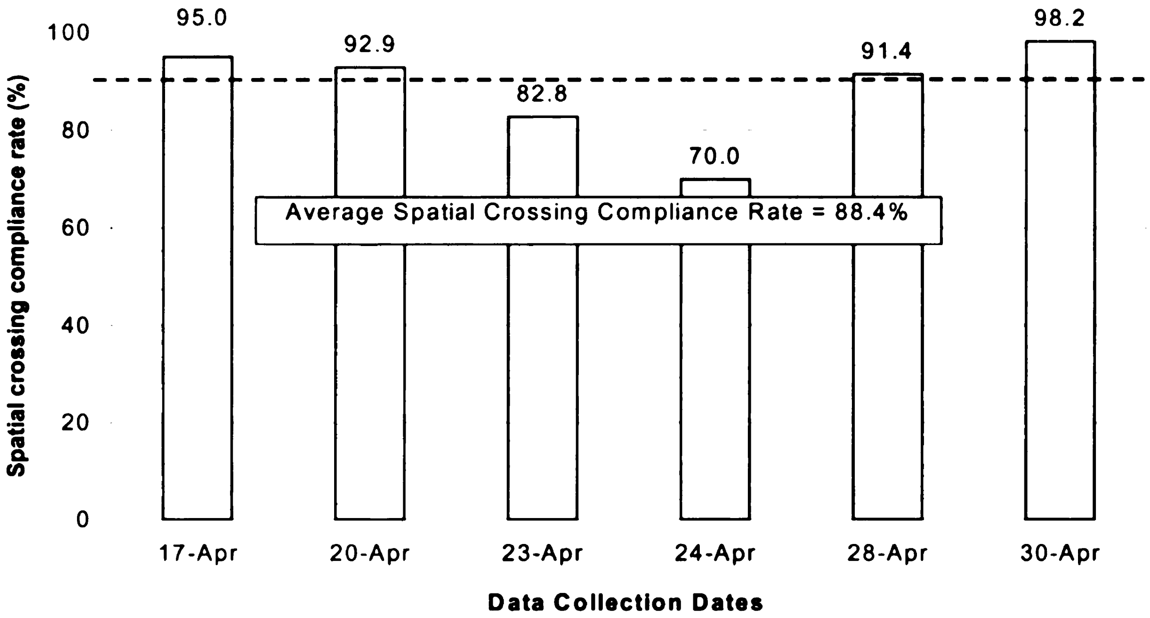

Figure E.5. Pedestrian compliance rates- Collingwood-west St signalized intersection crosswalk (compliance to location)

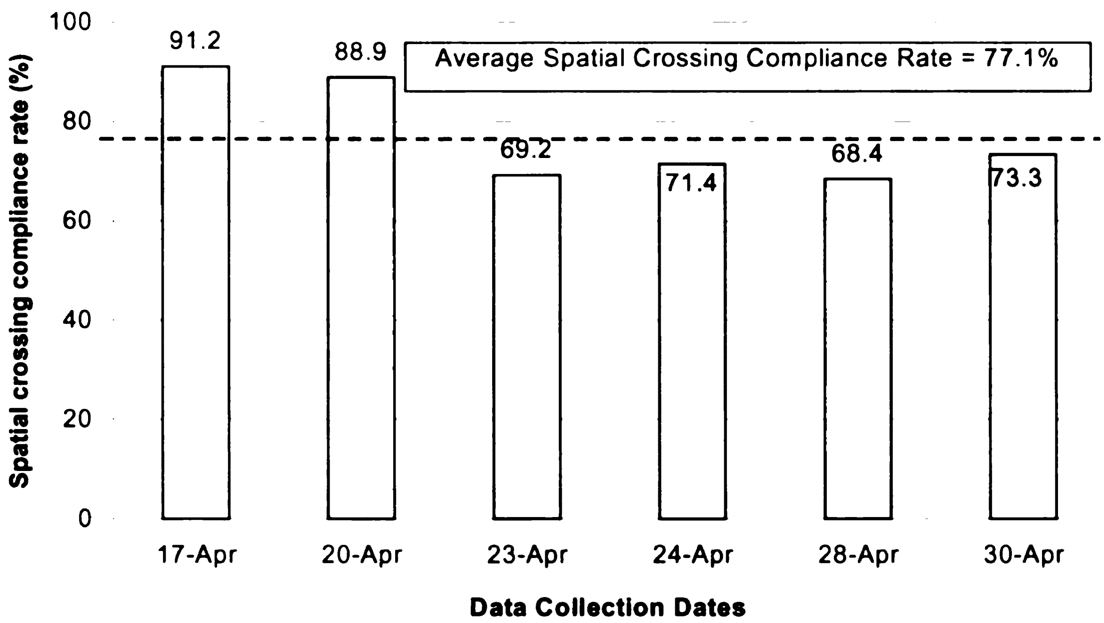

Figure E.6. Pedestrian spatial crossing compliance rates- Collingwood-east St signalized intersection crosswalk

APPENDIX F: Pedestrian Temporal Crossing Compliance Rates of all the Signalized Intersection Crosswalks

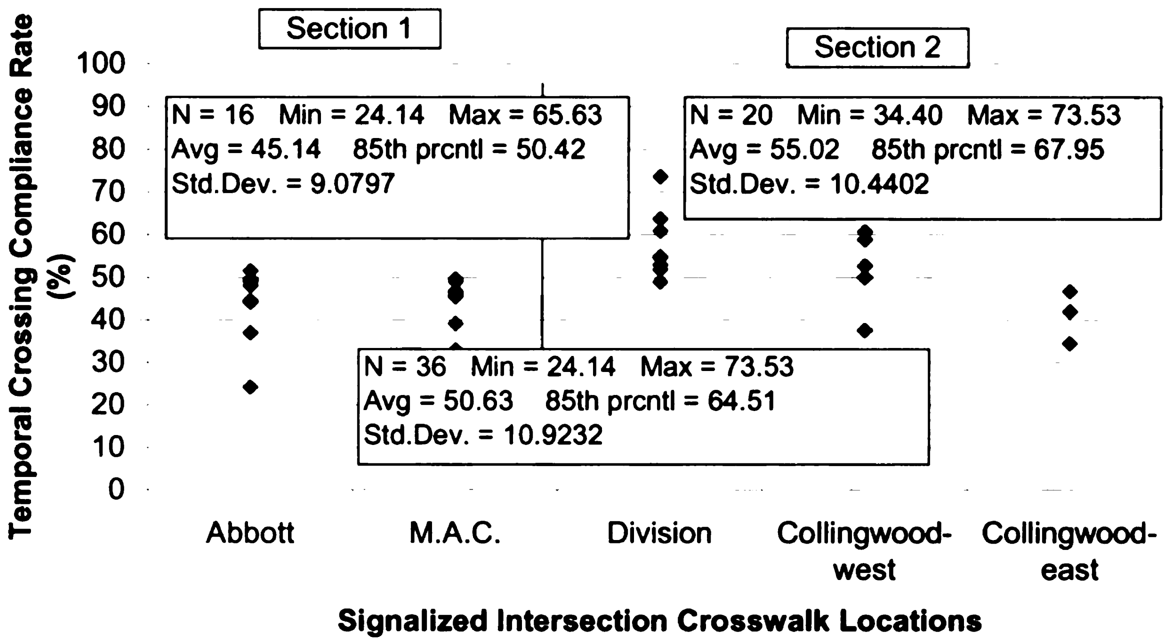

Figure F.1. Pedestrian temporal crossing compliance rates of all the signalized intersection crosswalks- all data collection sessions

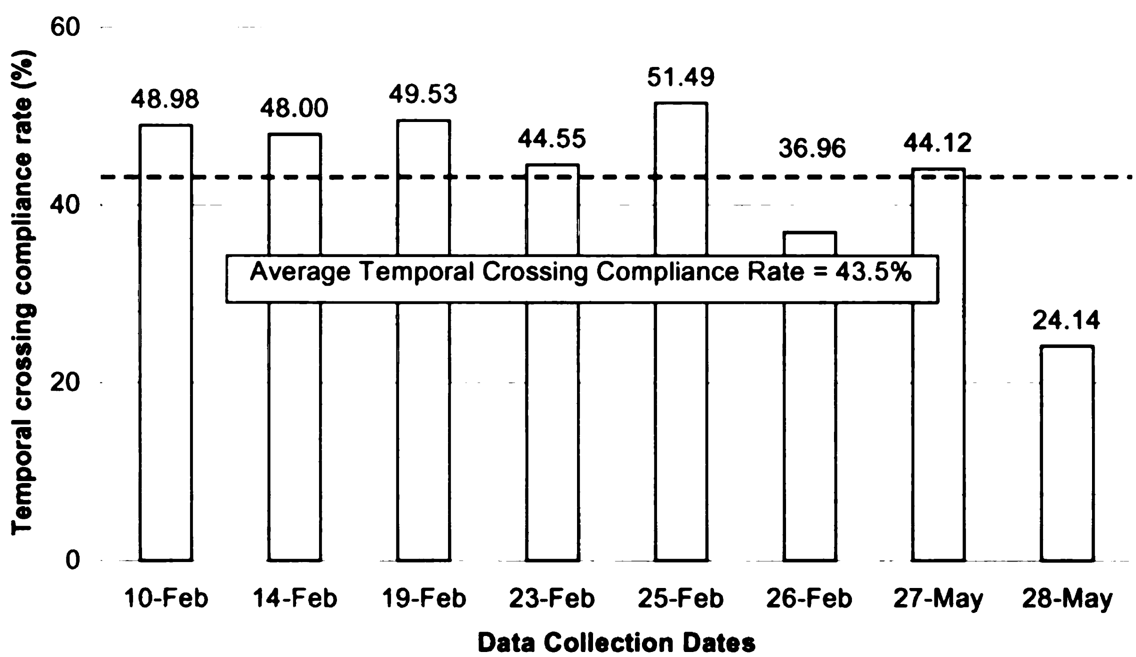

Figure F.2. Pedestrian temporal crossing compliance rates- Abbott St signalized intersection crosswalk

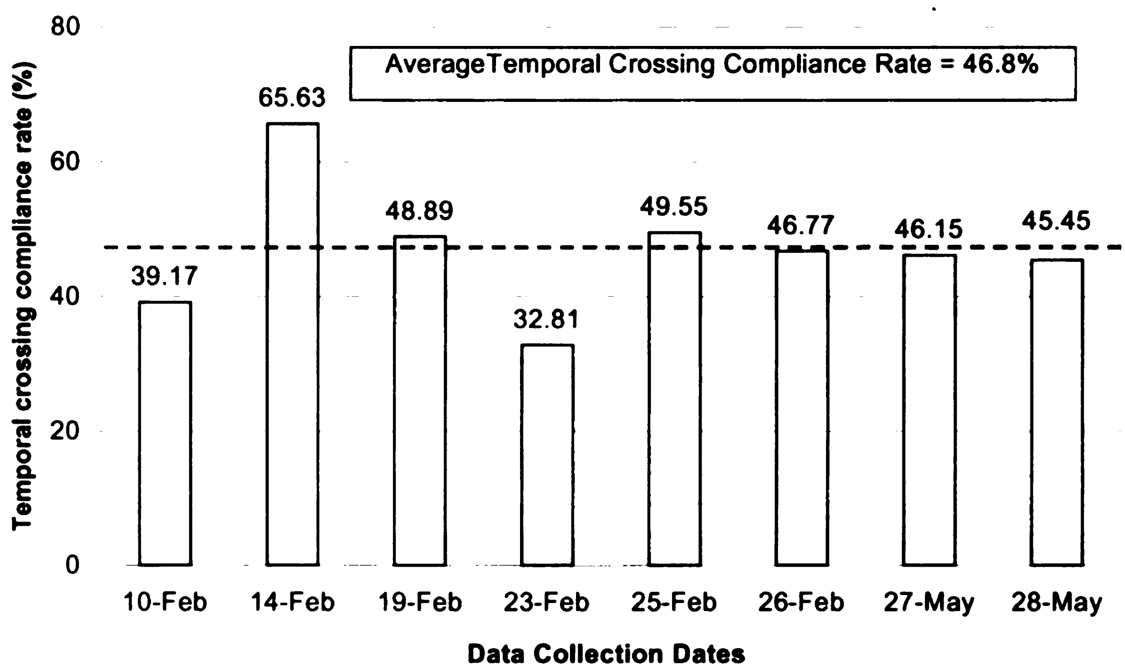

Figure F.3. Pedestrian temporal crossing compliance rates- M.A.C. Ave signalized intersection crosswalk

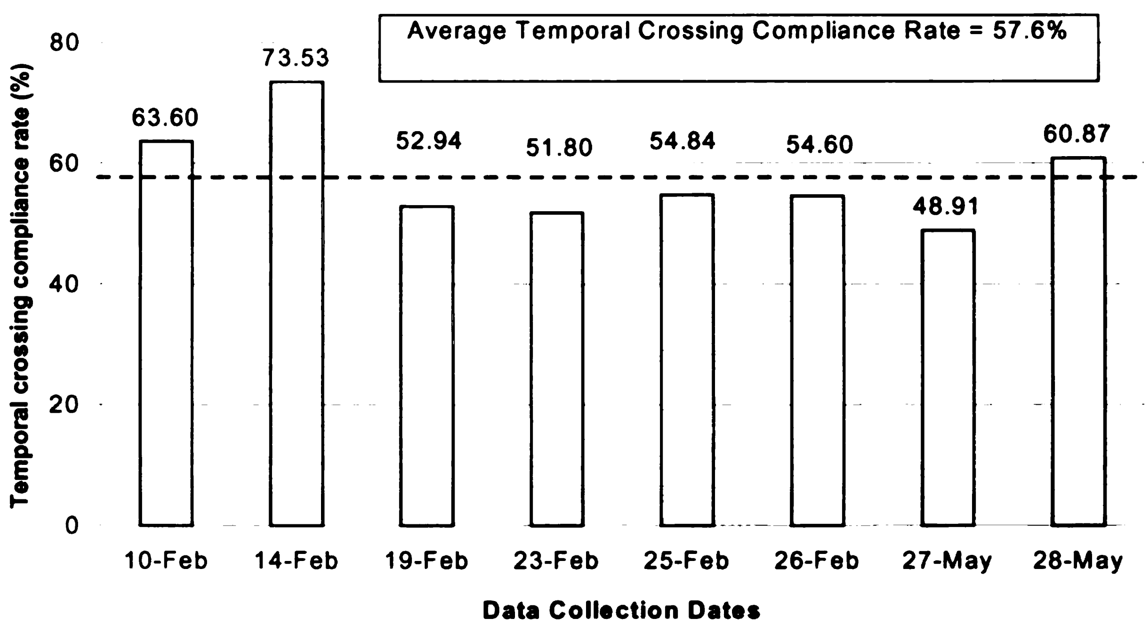

Figure F.4. Pedestrian temporal crossing compliance rates- Division St signalized intersection crosswalk

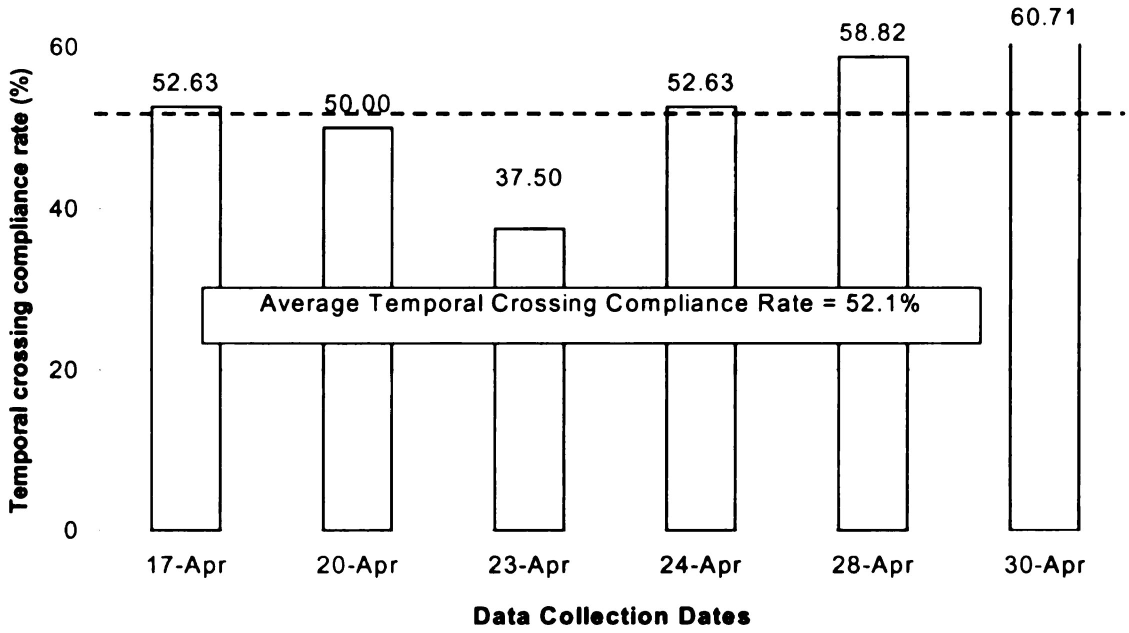

Figure F.5. Pedestrian temporal crossing compliance rates- Collingwood-west St signalized intersection crosswalk

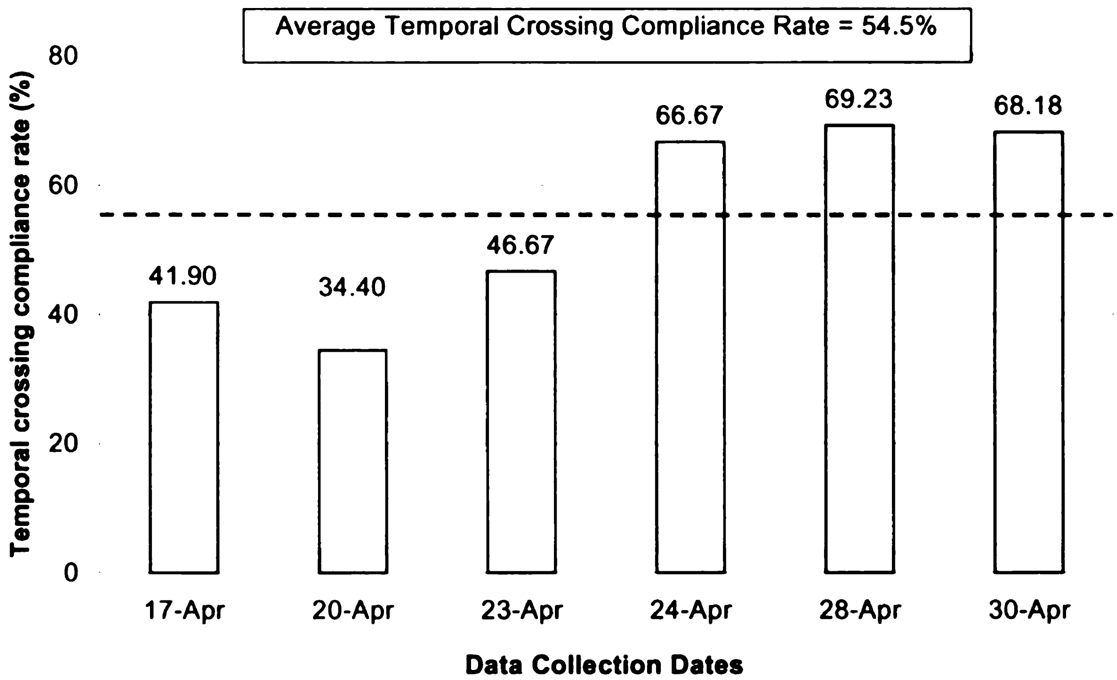

Figure F.6 Pedestrian temporal crossing compliance rates- Collingwood-east St signalized intersection crosswalk

APPENDIX G: Pedestrian Overall Crossing Compliance Rates of all the Signalized Intersection Crosswalks

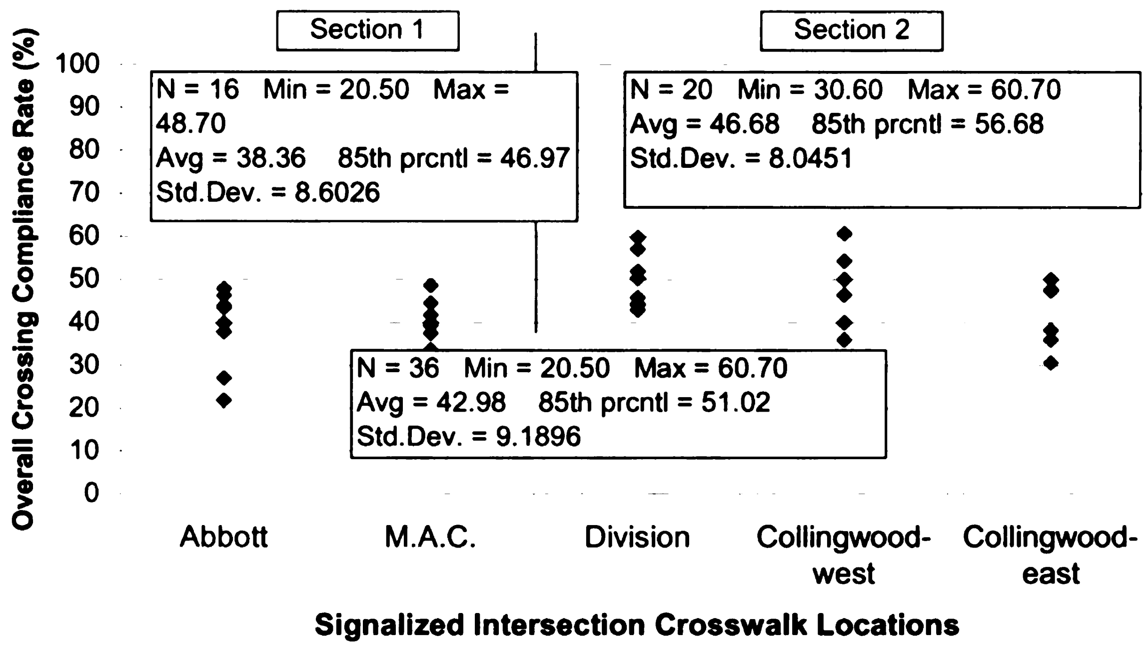

Figure G.1. Pedestrian overall crossing compliance rates of all the signalized intersection crosswalks- all data collection sessions

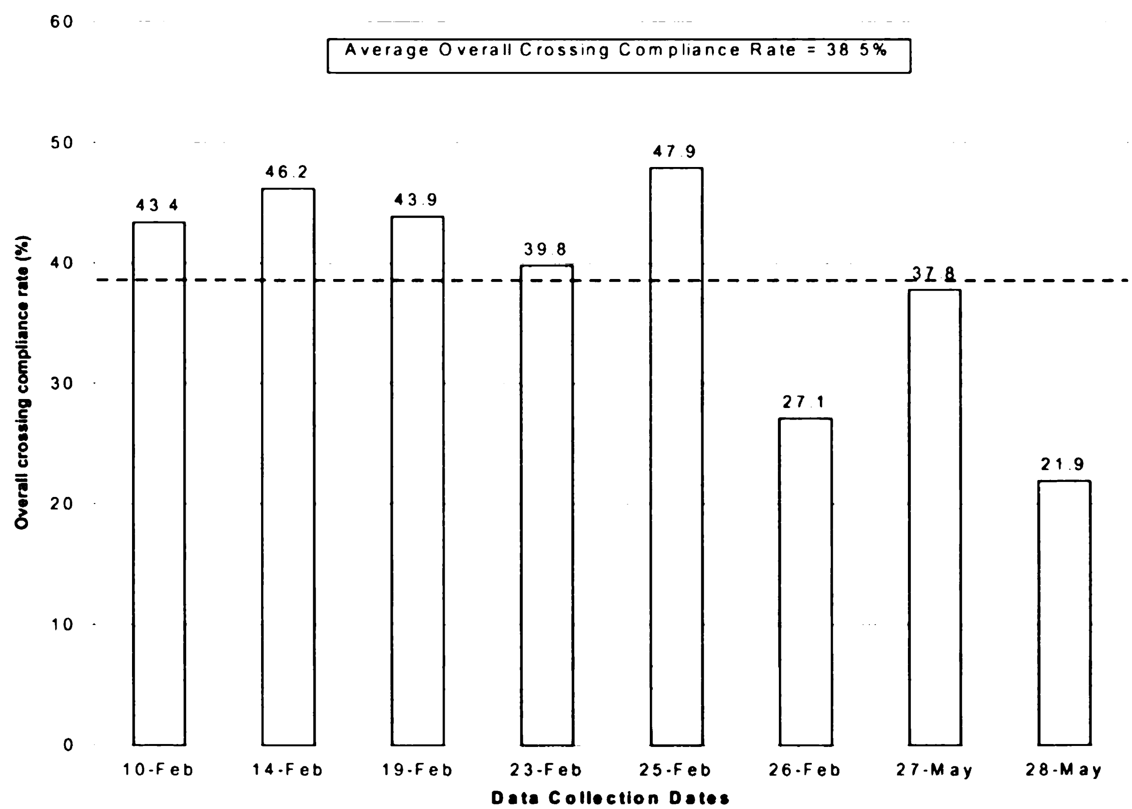

Figure G.2. Pedestrian overall crossing compliance rates- Abbott St signalized intersection crosswalk

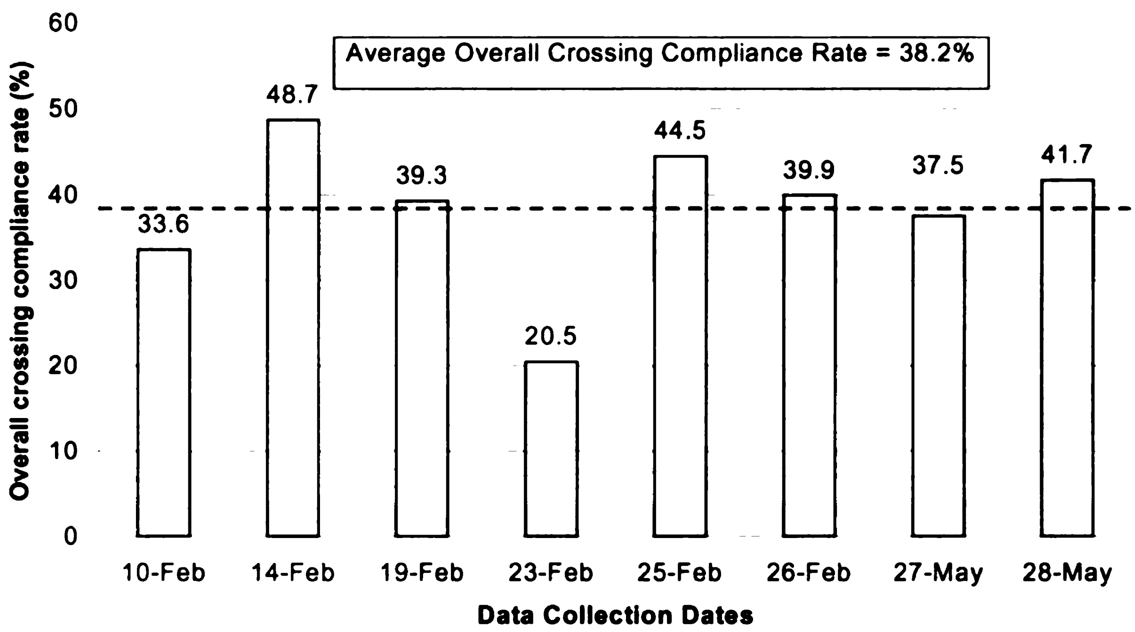

Figure G.3. Pedestrian overall crossing compliance rates- M.A.C. Ave signalized intersection crosswalk

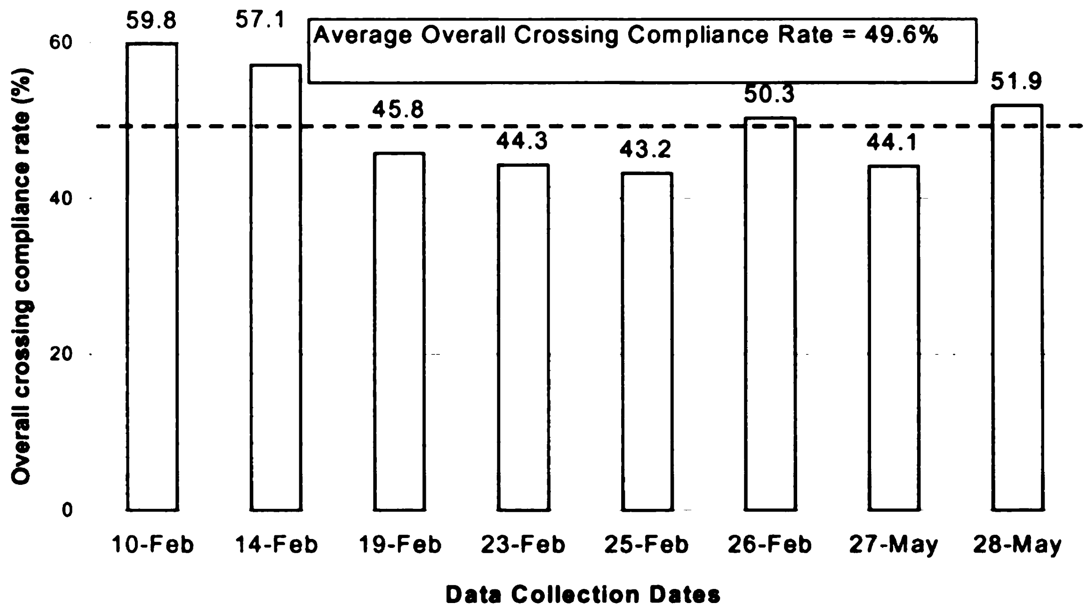

Figure G.4. Pedestrian overall crossing compliance rates- Division St signalized intersection crosswalk

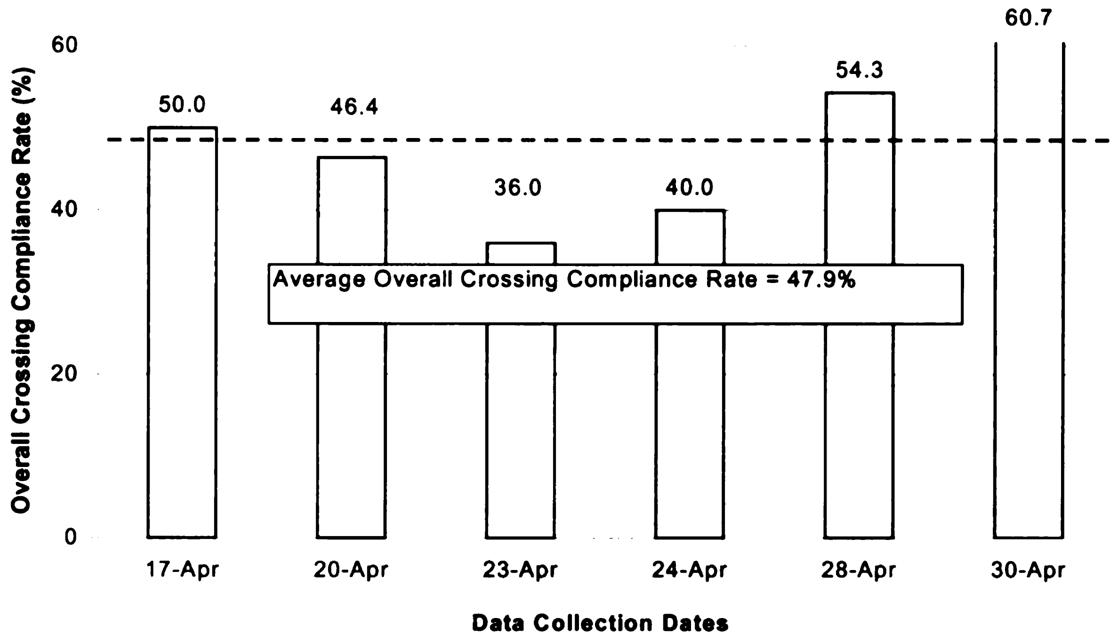

Figure G.5. Pedestrian overall crossing compliance rates- Collingwood-west St signalized intersection crosswalk

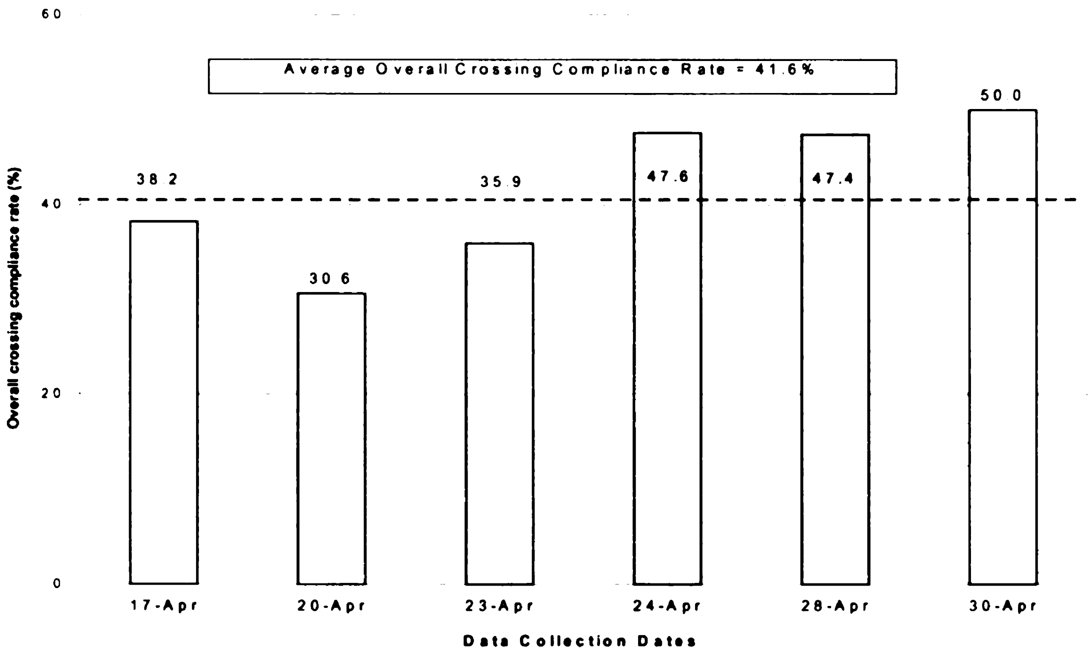

Figure G.6 Pedestrian overall crossing compliance rates- Collingwood-east St signalized intersection crosswalk