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Safety and Guidelines for Marked and Unmarked Pedestrian Crosswalks at Unsignalized Intersections in Nevada

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Disclaimer

SAFETY AND GUIDELINES FOR MARKED AND UNMARKED PEDESTRIAN CROSSWALKS AT UNSIGNALIZED INTERSECTIONS IN NEVADA

Final Report

Prepared for

NEVADA DEPARTMENT OF TRANSPORTATION

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PREFACE

This is the final report for the research project **Safety and Guidelines for Marked and Unmarked Pedestrian Crosswalks at Unsignalized Intersections in Nevada** sponsored by the Nevada Department of Transportation (NDOT).

In the United States, the loss of approximately 4,000 lives each year in pedestrian incidents is an awful toll. Even though the number of pedestrian fatalities fell from 5,585 in 1995 to 4,280 in 2010, there were still 59,000 pedestrian injuries reported each year. Although pedestrian injuries have been on a downward trend, only a fraction of pedestrian-related injury crashes were recorded by the police or hospitals. For the State of Nevada, there were 36 pedestrian fatalities and 180 serious injuries in 2009. While pedestrian-related crashes account for 6.7 percent of all traffic-related accidents in the State, they account for 42 percent of all traffic-related fatalities. The majority of pedestrian fatalities occurred at mid-blocks on a roadway, and a large percent occurred at stop-controlled intersections. An ongoing debate at such locations is whether a marked crosswalk should be provided and if so how effective it could be. Accordingly, NDOT needs to develop policies in an attempt to increase pedestrian safety and enhance mobility at unsignalized intersections.

Over the years, there have been controversial perceptions and study results regarding the safety performance of marked and unmarked crosswalks at unsignalized intersections. While marked crosswalks generally improve pedestrian mobility and provide a sense of security, several studies concluded that marked crosswalks involve higher pedestrian accident rates than unmarked crosswalks. Such controversial results make it difficult for state and local agencies to develop policies regarding the use of marked crosswalks. The Manual on Uniform Traffic Control Devices (MUTCD) provides limited guidance on the usage of marked crosswalks. In the MUTCD, crosswalk markings mainly serve as a device to define and delineate pedestrian paths. It does not address the safety concern of marked crosswalks. Currently, there are no specific uniform policies at NDOT and local agencies in Nevada regarding the use of marked or unmarked pedestrian crosswalks. The primary objective of this research is to fulfill such needs by developing a statewide, comprehensive guideline that provides a coordinated framework for installation of marked/unmarked crosswalks.

The report documents the findings and conclusions pertaining to the safety performance and selection of marked and unmarked crosswalks based on Nevada's conditions. Concerning the arrangement of the report, the executive summary presents how the research work was conducted throughout the two-year period and the conclusions drawn by executing each research task. The objectives and scope of this research are then stated in Chapter 2. Chapter 3 is a comprehensive literature review which documents previous research work concerning general guidelines and safety performance of marked and unmarked crosswalks to provide a valuable reference for this study. Chapter 4 focuses on the safety performance of marked crosswalks versus unmarked crosswalks in Nevada. Chapter 5 proposes an encompassing statewide guidance for marked and unmarked crosswalks at unsignalized intersections. In the end, all the findings and conclusions are summarized in Chapter 6.

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ABSTRACT

This report examines two aspects of marked and unmarked crosswalks at unsignalized intersections. Firstly, the report assesses the safety performance of marked/unmarked crosswalks in Nevada through comparing pedestrian-related crash rates. In which, a linear regression model is established to estimate pedestrian daily volume. Consistent with previous research, it is found that marked crosswalks do involve higher pedestrian-related crash rates in Nevada. In addition, the report proposes a set of guidelines for marking crosswalks at unsignalized intersections through a comprehensive process. It summarizes existing guidelines including the MUTCD guideline, FHWA guideline and etc. in the literature review. The report further points out that one of the major issues lies in the lack of comprehensive consideration and interpretation of potential factors. Considering safety and mobility effects, it suggests the contribution of each factor to the decision making not only depends on its own value but also the association with other factors. Hence, the report summarizes key impact factors and applies revised multi-criteria analysis methods to develop a Mark/Unmark Choice Tool embedded in the guideline. At last, the proposed guideline is applied in a case study involving field data in Nevada to demonstrate its practicability and feasibility.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 EXECUTIVE SUMMARY

The research project *Safety and Guidelines for Marked and Unmarked Pedestrian Crosswalks at Unsignalized Intersections in Nevada* was conducted in a two-year period from June 2010 to June 2012. The overall project was divided into several phases to achieve the research goals. With respect to the safety performance of crosswalks, a major data collection and analysis effort was involved. With respect to the guidance for installation of marked crosswalks, a comprehensive literature review of existing guidelines and research findings based on national and local studies was documented. Furthermore, a synthesis of the practice was assembled and guidelines applicable for Nevada were developed.

Firstly, the literature review focuses on research reports, journal publications, and materials found in the Internet. The first section of the review is related to guidelines for installing marked crosswalks at stop-controlled intersections and mid-block uncontrolled locations. It is found that the limited guidance in MUTCD are not sufficient to lead to a clear decision or interpretation concerning where a marked crosswalk should be placed. In reality, some traffic engineers have accepted the layouts of the FHWA guidelines incorporating key elements such as vehicle speed and ADT. However, other critical factors such as pedestrian demand, intersection geometry characteristics and safety concerns are not reflected in that guideline. The second section of literature is related to safety performance studies on marked and unmarked crosswalks. According to the literature, an inconsistency was found among previous studies regarding the safety merits of marking crosswalks. Although poor crash records of marked crosswalks were pointed out by several studies, the underlying reason varied. After all, the interpretation of crosswalk laws, pedestrians' attitudes and caution play a critical role.

The safety performance of crosswalks in Nevada was analyzed and the major data collection and analysis tasks were fulfilled. High pedestrian crash districts were enclosed in the major study areas, i.e. Las Vegas and Reno-Sparks-Carson areas. Correspondingly, high pedestrian crash locations were identified and designated as study sites. Concerning the safety performance measurement, the pedestrian-related crash rate was selected since it combines crash frequency (crashes per year) and pedestrian and vehicle exposures (pedestrian and traffic volumes). A significant difference between pedestrian-related crash rates at two types of crosswalks was found in Nevada's urban areas. Merely from the safety point of view, marked crosswalks did not fulfill their duty to preserve public safety. On the other hand, it pushes decision makers into an impasse.

Based on the comprehension of existing guidelines, a statewide guideline is put forward concerning the application of marked crosswalks in Nevada's urban unsignalized intersections. The guideline is based on the fundamental statement in MUTCD. Also, it follows the major findings from the synthesis and includes adequate adjustments based on the data analysis results in Nevada. In short, the substance of the guideline suggests the selection of marked crosswalks obey the following principles.

- Marked crosswalks must be installed carefully and selectively to guide pedestrians and warn vehicle drivers.
- Marked crosswalks must be installed after an engineering study confirms that the location is suitable for crosswalk markings.
- Marked crosswalks can be selected as a candidate at locations where,
    - There is substantial conflict between vehicular and pedestrian movements.
    - There is a need to direct a path for pedestrians considering the geometry layout of the intersection.

    - There is an unrestricted view of all pedestrians at all proposed crosswalk locations, for a distance not less than 200 feet approaching from each direction.
    - The location satisfies one of the specific parameter thresholds including (i) the vehicular speed limit is less than 40 mph; (ii) the distance to a nearby crosswalk is more than 200 feet; (iii) the vehicle ADT is less than 15,000.
- Marked crosswalks can ultimately be installed at candidate locations based on the Mark/Unmark Choice Tool recommendation.

The application of the guideline suggests that it is easy to manipulate and takes into consideration the major impact factors, such as vehicular traffic volumes, pedestrian volumes, site location, speed limit, and site geometry.

To conclude, this research focuses on one of the popular issues regarding pedestrian safety at unsignalized intersections. The decision of marking the crosswalks is somewhat subjective especially when both safety and mobility factors are concerned altogether. Therefore, this study developed a tool as guidance to interpret the dilemma of crosswalk markings.

2 INTRODUCTION

2.1 Background

The development (design) and management (maintenance/upgrade) of transportation systems must explicitly address both mobility and safety considerations. A pedestrian is a legitimate road user; therefore, providing safe and convenient crosswalks for pedestrians to cross roadway facilities must be an important issue for transportation agencies.

Pedestrian injury and fatality rates in Nevada's urban areas are among the highest in the nation. In addition, pedestrian crashes have been the leading cause of traffic fatalities in Nevada's urban areas. Each year, more than 500 pedestrians are killed or injured in Nevada's urban areas, and the majority of these pedestrian accidents occur at intersections and midblock crossings. As a result, the Nevada Strategic Highway Safety Plan (SHSP) has identified reducing pedestrian fatalities as being a major strategic goal. Pedestrian crashes occurring at stop-controlled intersections and midblock crossings not only highly contribute to the total number of crashes, but also result in more severe injury or fatal crashes. One of the critical aspects of crosswalks at such locations is whether they should be marked or not.

Over the years, research work kept proposing arguable perceptions and opinions pertaining to the safety merits of marked crosswalks. At unsignalized intersections, marked crosswalks can be provided on either one approach of a major-street or both approaches according to the volume and interaction between pedestrian and driver. The purpose of marking the crosswalk is to provide a path in order to direct pedestrians to pass through. Not only should the mobility be enhanced, but safety should also be preserved. While marked crosswalks generally improve pedestrian mobility and provide a sense of security, several studies concluded that marked crosswalks generally involve higher pedestrian accident rates than unmarked crosswalks.

The MUTCD provides restrict guidance on the usage and design of marked crosswalks. In the MUTCD, crosswalk markings mainly serve as a device to define as well as delineate pedestrian paths. Therefore, places where substantial conflicts between pedestrians and drivers occur should prefer marked crosswalks since they might warn drivers and also guide pedestrians. But there is no elaboration to how many pedestrians would generate substantial conflicts. Normally, engineering judgments are applied for a specific site to decide the desirable crosswalk type for traffic/pedestrian safety and mobility. This decision-making process lacks a scientific principle and the consequences are unimaginable since the immediate impact is pedestrian safety.

In general, agencies within Nevada are applying some basic guidelines while deciding whether to mark a crosswalk. For instance, the City of Reno is executing a Scored System, and Clark County is applying a policy stating that a crosswalk should be marked if pedestrian demand exceeds 20 pedestrians per day. However, some of the guidelines or policies are not documented or not in detail. Most agencies in Nevada are starved of a statewide guidance to help promote the uniformity in application of pedestrian crosswalk markings.

2.2 Objective and Scope

Currently, there are no specific policies in NDOT and local agencies regarding the use of marked or unmarked pedestrian crosswalks. Neither have any Nevada based studies concerning the safety performance of marked or unmarked crosswalks at unsignalized intersections been conducted. Nevada uses different markings than other states where the safety of different markings has been studied, such as California. Thus, this research work will provide policy guidance to specifically address this issue, i.e., under what conditions marked pedestrian crosswalks should be used, and how the markings on crosswalks contribute to the overall pedestrian safety. The primary research objectives are:

- To investigate whether there is a difference in safety performance at marked and unmarked pedestrian crosswalks in Nevada's urban areas.
- To develop a set of guidelines for installing marked crosswalks at unsignalized intersections.

The developed guideline ought to guide transportation planners and engineers to select crosswalk types to accommodate all users. To accomplish the objectives, the guidelines need to be developed based on the following principles:

- Crosswalk markings aim at providing guidance for pedestrians who are crossing unsignalized intersections by defining and delineating paths within the intersections.
- Crosswalk markings aim at serving to alert road users of a pedestrian crossing point in front of the unsignalized intersections.
- Crosswalk markings legally establish the crosswalk at unsignalized intersections.
- Crosswalk markings do not guarantee pedestrian safety.

This research work focuses on unsignalized intersections including Two-way Stop-controlled, All-way Stop-Controlled and Un-Controlled intersections. But mid-block locations and non-intersection locations are not contained. In addition, the design of the marking, for instance, the dimensions, painting materials, marking types and placing spot are out of the scope of this study. The main product of this study is a set of guidelines developed concerning the selection of marked crosswalks.

3 LITERATURE REVIEW

The original intention of marking crosswalks is to guide pedestrians and also reduce the potential conflict of vehicles and pedestrians. However, over the past several decades, there have been controversial perceptions and study results concerning the performance of marked and unmarked crosswalks at unsignalized intersections that challenged this elementary purpose. In short, since 1960, several study results have come up with the conclusion that marked crosswalks involve higher pedestrian accidents than similar unmarked crosswalks although marked crosswalks provide a sense of security (*1*, *2*, *3*, *4*, *5*, *6*). Almost all of the studies conducted in other states in the United States, like California, Florida, and Texas have shown this consistent result which leads the state and local government to consider the option of removing marked crosswalks unless they meet certain warrants. Therefore, transportation engineers and planners are facing a significant dilemma on the installation of marked crosswalks.

This literature review summarizes general guidelines for marking crosswalks and the features that researchers in other states recommended to improve pedestrian safety at marked crosswalks. In addition, previous works done in the field of safety performance of marked and unmarked crosswalks are encapsulated to provide background and reference materials for this study. In this process of literature review, case studies conducted in the United States and overseas countries are reviewed as well.

3.1 Introduction

3.1.1 Definition of a Crosswalk

In Nevada Revised Statutes (NRS) 484A.065 part (*7*), a crosswalk is defined as:

(1) That part of a highway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or, in the absence of curbs, from the edges of the traveled portions of highways; or

(2) Any portion of a highway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface.

Thus, a crosswalk at an intersection is defined as the extension of the sidewalk or the shoulder across the intersection, regardless of whether it is marked or not. Most jurisdictions have crosswalk laws that make it legal for pedestrians to cross the street at any intersection, whether marked or not, unless the pedestrian crossing is specifically prohibited (*8*).

Generally, marked crosswalks are described as painted pedestrian crossings that specify proper locations for pedestrians to cross the street. Since in most of the articles, the dimensions of the crosswalk markings were not given, Stites et al. mentioned that they were standard 300 millimeters (12 inches) wide marking lines during a study funded by Caltrans (3). Figure 1 shows different crosswalk markings in use within the United States. The research conducted in other states evaluated the types of markings utilized in the states research.

The costs of marking a crosswalk range from $100 for a regular striped crosswalk to $300 for a ladder crosswalk to $3,000 for a patterned concrete crosswalk (*9*). Maintenance costs should also be considered based on the paint material used.

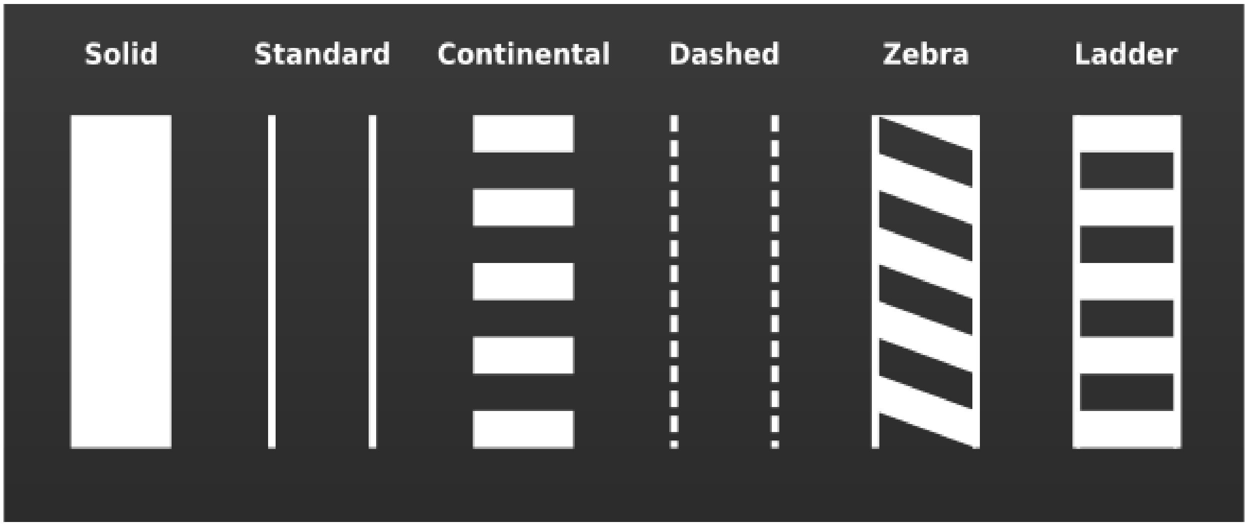

Figure 1 Different Crosswalk Markings in Use in the United States

3.1.2 Existing Discussions

Crosswalks at unsignalized intersections have become the subject of numerous studies over the past 30 years. One of the critical aspects of pedestrian crosswalks at unsignalized intersections is whether they should be marked or not. As Zegeer, et al. (8, *8*) and others have argued, "Pedestrians have a right to cross roads safely and, therefore, planners and engineers have a professional responsibility to plan, design, and install safe crossing facilities." Marking the crosswalks at such locations is surely one of the forthright choices. However, inadequate pedestrian safety in marked crosswalks at unsignalized intersections continues to challenge transportation engineers and planners.

In general, the public tends to place a great amount of confidence in marked crosswalks as safe devices. One outcome of this opinion is that more and more pedestrian crosswalks are being marked in response to citizen complaints or political pressure (3). However, this may cause misuse of marked crosswalks, particularly at unsignalized intersections.

For one thing, former study results showed that marked crosswalks always revealed poor safety performance compared with unmarked ones especially at unsignalized intersections and midblock crossing locations (1, 2, 3). This is the main reason that researchers and engineers question the large usage of marked pedestrian crosswalks. Frequently, there are differences among locations, data collection techniques and statistical analysis methodologies in these studies, but they concluded that indeed there were higher rates of pedestrian accidents at marking pedestrian crosswalks.

For another concern, pedestrians and drivers can easily get confused about the right-of-way laws at marked crosswalks which might present diverse behaviors. Researchers can analyze different accident rates between marked and unmarked crosswalks through interpreting both pedestrians' and drivers' behaviors and understanding of right-of-way laws. For instance, marked crosswalks provide a sense of security to pedestrians. Therefore, they choose to believe that as long as they walk across the street at those marked lines, they have the right-of-way. Nevertheless, drivers may not always notice the marking lines at intersections, especially unsignalized intersections or they may fail to yield to pedestrians since they always say that "they do not see them." Under such conditions, the drivers probably suppose that they have the right-of-way. Thus, it seems that both pedestrians and drivers have their own defense.

3.1.3 Advantages and Disadvantages

The guide developed by the Pedestrian and Bicycle Information Center (PBIC) in collaboration with SRTS experts from around the country, and also supported by the National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration (FHWA), Centers for Disease Control and Prevention (CDC) and Institute of Transportation Engineers (ITE) (*10*), pointed out that properly placed marked crosswalks will encourage pedestrians to walk at preferred crossing locations while increasing the visibility of a pedestrian crossing and driver awareness. However, marked pedestrian crosswalks, do not slow traffic or reduce pedestrian crashes. In other words, there is no proven reduction in pedestrian crashes resulting from marking crosswalks without adding other more substantial crossing treatments such as raised medians, traffic and pedestrian signals or improved nighttime lighting. Both advantages and disadvantages are reasonably summarized by Herms in 1972 (1).

Advantages of marked crosswalks

- Help pedestrians orient themselves across complex intersections;
- Show the shortest route across traffic;
- Show the route with the least exposure to vehicular traffic and traffic conflicts;
- Show the oncoming traffic the positions of pedestrians;
- Help channelize and limit pedestrian traffic to specific locations;
- Aid in enforcing pedestrian crossing regulations;
- Shown as a warning device and reminder to motorists that this is the location where pedestrian conflict can be expected.

Disadvantages of marked crosswalks

- Cause pedestrians to have a false sense of security and place themselves in a hazardous position with respect to vehicular traffic;
- Cause pedestrians to think that the motorist can and will stop in all cases, even when it is impossible to do so;
- Cause a higher number of rear-end and associated collisions due to pedestrians not waiting for gaps in traffic;

- Cause an increase in fatal and serious-injury accidents;
- Cause an increase in community-wide accident insurance rates;
- Cause disrespect for all pedestrian regulations and traffic controls;
- Cause an increased expense to taxpayers for installation and maintenance costs that may not be justified in terms of improved public safety.

To sum up, marked crosswalks exhibit deficient security at unsignalized intersections compared to unmarked crosswalks according to several noteworthy studies. Nevertheless, other study results favor marked crosswalks. This is the main controversial argument around this topic. Additionally, government and agencies in states cannot guarantee that removing these markings at such locations will reduce accident rates. Therefore, studies in two branches are generated. One is developing guidelines to provide basic clues for installing marked crosswalks. Another is aimed at seeking the explanations and possible influence factors, such as human cognitive factor, which can give reason to the different performance of marked versus unmarked crosswalks.

3.2 Existing Guidelines

Over the years, studies conducted in the United States and overseas countries have advanced several principles helping governments decide under what conditions markings would be a better choice. Some of these guidelines have similarities in ordinary parts, yet others may be particular to their own traffic and safety situations. In spite of this, those general guidelines present beneficial reference for this study.

3.2.1 General Guidelines

In the Manual on Uniform Traffic Control Devices (MUTCD) Section 3B-18 (*11*), the purposes of crosswalk markings are stated as:

> *"Crosswalk markings at signalized intersections and across intersection approaches on which traffic stops, serve primarily to guide pedestrians in the proper paths. Crosswalk markings across roadways on which traffic is not controlled by traffic signals or STOP signs, must also serve to warn the motorist of a pedestrian crossing point. At non-intersection locations, these markings legally establish the crosswalk."*

Also, the MUTCD provides some general guidelines regarding pedestrian crosswalks in Part 3B.17 (*11*),

> *"Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops.*
>
> *Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by traffic signals or STOP signs.*
>
> *At intersection locations, crosswalk markings legally establish the crosswalk".*

It further provides the general guidelines for installing marked crosswalks (*11*):

> *"Crosswalks should be marked at all intersections where there is substantial conflict between vehicular and pedestrian movements. Marked crosswalks also should be provided at other appropriate points of pedestrian concentration, such*

as at loading islands, midblock pedestrian crossings, or where pedestrians could not otherwise recognize the proper place to cross.

Crosswalk lines should not be used indiscriminately. An engineering study should be performed before they are installed".

As determined by the Federal Highway Administration (FHWA) Interpretation Letter 3-178 (I) (*12*), colored paint between the white lines of a crosswalk marking is permitted, as long as the paint does not:

- Degrade the contrast of the white lines.
- Use colors that may be misconceived by drivers as traffic control device.
- Contain retro reflective materials.

A complement of foregoing general guidelines put forward by Zegeer and colleagues in a FHWA project (8) divided crosswalks into three possible ratings, which are:

- **C: Candidate sites for marked crosswalks.** Marked crosswalks must be installed carefully and selectively. An engineering study is needed to determine whether the location is suitable for a marked crosswalk before installing new marked crosswalks.
- **P: Probable increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements.** These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.
- **N: Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone.** Consider using other

treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvements to improve safety crossing for pedestrians.

They pointed out that marked crosswalks should not be overused. The recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled intersections are shown in Table 1. This rating system has been adopted and incorporated into the 2001 Traffic Control Device Handbook, which is designed to augment MUTCD (*11*). The system is intended to provide initial guidance on whether an uncontrolled location might be a candidate for a marked crosswalk alone and/or whether additional enhancements may be desirable (8). However, the letter "N" indicating marked crosswalks alone are insufficient, applies only if speed is relatively high and it seems irrelevant to vehicle and pedestrian volumes in this guideline.

Moreover, the ladder and diagonal markings are listed in the MUTCD as high visibility crosswalks (*11*). Even though no differences in pedestrian crash risk have been found between parallel crosswalk lines and high visibility markings, they are becoming more commonly used by some local agencies in recent years (e.g., Orlando, Florida, and Cambridge, Massacusetts) (*10*).

In summary, pedestrian crosswalks should be marked to guide pedestrians and alert drivers to a crossing location so that they should be clearly seen by both drivers and pedestrians. Also, marked crosswalks should be designed to minimize crossing distances and should be straight, to make them easier for pedestrians with visual impairments to navigate (*10*). Apparently, limited guidelines in MUTCD are not sufficient to lead to a clear interpretation respecting where marked crosswalks should be placed. There are several studies pertaining to marking crosswalk guidelines within the United States that can be utilized as references.

Table 1 Volume, Lane, and Speed Limit-based Guidelines for Crosswalk Installation

Roadway Type (Number of travel lanes and median type)	Average Daily Traffic (ADT)<9,000			ADT>9,000 to 12,000		
	Speed Limit					
	<30mph (48.3 km/h)	35mph (56.4 km/h)	40mph (64.4 km/h)	<30mph (48.3 km/h)	35mph (56.4 km/h)	40mph (64.4 km/h)
2 lanes	C	C	P	C	C	P
3 lanes	C	C	P	C	P	P
Multilane (4 or more lanes) with raised median	C	C	P	C	P	N
Multilane (4 or more lanes) without raised median	C	P	N	P	P	N
Roadway Type (Number of travel lanes and median type)	Vehicle ADT > 12,000 to 15,000			Vehicle ADT> 15,000		
	Speed Limit					
	<30mph (48.3 km/h)	35mph (56.4 km/h)	40mph (64.4 km/h)	<30mph (48.3 km/h)	35mph (56.4 km/h)	40mph (64.4 km/h)
2 lanes	C	C	N	C	P	N
3 lanes	P	P	N	P	N	N
Multilane (4 or more lanes) with raised median	P	P	N	N	N	N

Note: *These guidelines include intersection and midblock locations without traffic signals or stop signs on the approach to the crossing, nor school crossings. Where the speed limit exceeds 40 mph (64.4 km/h), a marked crosswalk alone should not be used at unsignalzied locations. The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines. The letters C, P and N in the table represent* candidate *sites for marked crosswalks, sites where probable increase in pedestrian crash risk may occur, and sites where marked crosswalks alone are insufficient, respectively.*

3.2.2 Guidelines from Previous Research

More and more researchers and engineers keep suggesting that there is a need to make a specific set of guidelines to help reduce the number of marked crosswalks which might have been placed in inappropriate situations. Due to the lack of specific unified guidelines for an entire state regarding the placement of marked crosswalks, individual states have initiated the developing of their own guidelines or warrants according to their situations and based on their own judgments and knowledge.

Several agencies use general warrants to determine whether or not marked crosswalks are needed (3). Some engineers prefer that crosswalks should be marked at locations with higher pedestrian and vehicular traffic volumes and should not be marked at locations with lower volumes. Nonetheless, the issue is that marked crosswalks are sometimes found at low volume levels, yet unmarked ones are found at high volume locations. On account of inconsistent practice, states and agencies conduct research to form guidelines for marking pedestrian crosswalks which shed new light on the mark versus unmark debate (8).

The remarkable study worthy of referencing, Pedestrian Crosswalk Study: Crashes in Painted and Unpainted Crosswalks by Herms in 1972 delivered several recommendations for the placement of crosswalk markings. At first, existing crosswalk warrants should be reviewed and updated, and special consideration should be given to pedestrian channelization needs, nighttime illumination, vehicle approach speed, and motorist inability to see pedestrians or the crosswalk at the critical safe stopping distance. In addition, no new crosswalks should be installed unless they meet the conditions established by the warrants. Furthermore, existing crosswalks should be reevaluated to see whether they meet the revised warrants (1).

In addition, Knoblauch et al. (*13*) developed a set of guidelines to determine what type of markings should be provided while conducting their project in 1988. Their guidelines were based on the work by Smith and Knoblauch in 1987, which contained a survey of local practitioners and an examination of relevant pedestrian research (*14*). In other words, their guidelines were not based on either pedestrian accident occurrence or pedestrian-vehicle conflicts.

They first formed a general guideline, and then showed it to approximately thirty practitioners to come up with their final guidelines based on survey comments. Practicing traffic engineers in nine geographically diverse state and municipal agencies were contacted to determine current operational practices pertaining to the installation of crosswalk markings (*13*). Those practitioners were asked specific questions about the following:

- Warrants, guidelines, and criteria used for installing marked crosswalks;
- Any problems involved in applying those warrants;
- What factors or criteria should be considered in developing non-crosswalk warrants?

From practitioners' response, several aspects should be considered while setting up guidelines. First of all, most of the practitioners did not use specific quantitative procedures for the application of crosswalk markings. That means they will consider more qualitative analysis, such as human factors. Secondly, when it comes to areas within school routes and signalized intersections, nearly all practitioners choose marked crosswalks. Furthermore, three of the practitioners considered pedestrian volumes while determining marking or not and one specifically quantified the minimum pedestrian volume warrant at 100 pedestrians/day. In addition, some practitioners used a "point" warrant systems while others did not (*13*). In conclusion, the majority of them recommended some factors, such as vehicle volumes, pedestrian volumes, vehicle speed limit and sight distance to be included in a new crosswalk warrant system.

While establishing guidelines and warrants for installing crosswalk markings, several information sources were summarized for useful knowledge. The sources included considering pedestrian and vehicular volumes whether to mark crossings as quoted from Tobey et al.; Smith and Knoblauch's work in 1987 (*14*). A summary of several existing warrants from outside the United States is included, which could be used to establish the volume threshold curves and etc.

Moreover, the study conducted by Zegeer et al. for the Federal Highway Administration also provided guidelines for installing crosswalks. This study was based on five years of pedestrian-related crash data in 1,000 marked crosswalks and 1,000 unmarked crosswalks used as comparison sites in 30 U.S. cities (8). However, this study did not include any sites in the State of Nevada. In their guidelines, they recommended that marked pedestrian crosswalks may be used to delineate safe pedestrian paths across roadways under the following three conditions:

- *At locations with stop signs or traffic signals to direct pedestrians to those crossing locations and to prevent vehicular traffic from blocking the pedestrian path while stopping for a stop sign or red light.* Under this condition, marking crosswalks may help to reduce occurrence of accidents.

- *At non-signalized crossing locations in designated school zones.* If needed, adult crossing guards, school signs, and/or traffic signals with pedestrian signals (when warranted) should be used in conjunction with the marked crosswalk.

- *At unsignalized locations* where engineering judgment dictates that the number of motor vehicle lanes, pedestrian exposure, average daily traffic (ADT) , posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Besides the above-mentioned general guidelines, they also recommended that without traffic calming treatments or other substantial crossing improvements, marked pedestrian crosswalks alone are insufficient and should not be used under the following three conditions based on the analysis of pedestrian crash experience, pedestrian exposure data, as well as study site conditions (8):

- Where the speed limit exceeds 40 mph (64.4 kmph);
- On a roadway with four or more lanes <u>without</u> a raised median or crossing island that has (or will soon have) an ADT of 12,000 or greater;
- On a roadway with four or more lanes <u>with</u> a raised median or crossing island that has (or will soon have) and ADT of 15,000 or greater.

Similarly, Fitzpatrick et al. provided pedestrian crossing installation guidelines in "Improving Pedestrian Safety at Uncontrolled Crossings" (*15*). The places where markings are generally used included:

- Signalized intersections with pedestrian signal indications or substantial pedestrian crossings;
- Places where marked crosswalks can concentrate or channelize multiple pedestrian crossings to a single location;
- Places where there is a need to delineate the optimal crossing location when it is unclear because of unusual geometric layout, sight distance, or traffic operations;
- Approved school crossings or for crossings on suggested safe routes to school;
- Other locations with significant pedestrian crossings and potential for pedestrian vehicle conflicts.

In conclusion, there are no uniformly accepted guidelines or warrants pertaining to the crosswalk marking issue. States and agencies prefer to conduct engineering studies to decide whether marking is needed or not. On account of limited descriptions in MUTCD, researchers and engineers conducted several projects to develop their own guidelines. In the process, several variables such as traffic volumes and intersection geometric layout are involved. However, the majority of these guidelines did not mention any explanations concerning the safety performance of marked crosswalks. And no assumption was made as to whether marked or unmarked crosswalks were safer before conducting the studies.

Since Zegeer and colleagues have made an adequate complementary of safety enhancement recommendations for crosswalk facilities, later research continues in this field in two primary areas. One is to clarify and supplement the recommended engineering countermeasures from the Zegeer study. The other is to analyze the underlying behavioral characteristics that may contribute to pedestrian collisions and better inform the selection of countermeasures (*16*). The following sections will focus on studies and contributions in these aspects.

3.3 Safety Performance

The most concerned aspect of a pedestrian crosswalk marking is whether it improves the safety at pedestrian crossings (3). Several agencies tend to install marked crosswalks at most intersections and major midblock crosswalk locations with the expectation of improving pedestrian safety and mobility (8). However, many professionals doubt about whether markings at crosswalks mean more safety for both pedestrians and drivers. Hence, studies on the safety performance of marked and unmarked crosswalks attract more effort and attention.

For years, there have been controversial studies on this topic. Some indicated that marked crosswalks often reveal poor safety performance compared with similar unmarked crosswalks. On the contrary, others indicated crosswalk markings did enhance safety at intersections. As to the negative findings, assertions were made that marked crosswalks somehow induced incautious behavior on the part of pedestrians (8). There have been fewer studies regarding driver behavior and thus driver's behavior at such locations is not as clear. In spite of these contradictions, all of the research efforts made extraordinary contribution in this field. They provide guidance related to how this issue has been treated and what methodologies could be applied to help solve this problem.

3.3.1 Crash Studies

Marked Crosswalks

An early and often-quoted study is that by Herms in 1972 (1). Pedestrian related accident data in San Diego was collected in the 1960's for a five-year period to investigate the possible difference between crash risk at marked and unmarked crosswalks. This study chose 400 unsignalized intersections where one crosswalk was painted and another was not, and both the painted and not painted crossed the major flow of traffic. Thus, the traffic exposure was between the marked and unmarked crosswalks. It emphasized maintaining equivalent conditions in comparing marked and unmarked crosswalks, and further listed 12 factors to try and address such difficulties (8). This study also conducted a 24-hour manual pedestrian count at forty of the intersections to obtain a sample of the number of pedestrians using marked crosswalks versus unmarked crosswalks (1).

The results showed that pedestrian volume was three times as high on the marked crosswalks as on the unmarked ones. Total fatal pedestrian accidents occurring in the chosen 400 intersections were six times in marked crosswalks to one in the unmarked crosswalks. Also, pedestrian accidents, including fatal and non-fatal, happened in marked crosswalks were 5.7 times to those in unmarked crosswalks. In the meantime, 2.9 times more pedestrians prefer to use marked crosswalks than unmarked ones (1). Based on the results, they concluded that there were twice as many pedestrian related accidents than unmarked crosswalks. Very young and very old pedestrians in both marked and unmarked crosswalks were involved in the highest number of pedestrian accidents. Herms stated:

> *"Evidence indicates that the poor crash record of marked crosswalks is not due to the crosswalk being marked as much as it is a reflection on the pedestrian's attitude and lack of caution when using the marked crosswalk."*

It can be seen that they made an assumption before starting the study that pedestrians seem to be less cautious at marked crosswalks. However, they did not mention the reason for less cautious pedestrian behavior since no behavioral data were collected or presented, even though other authors have advanced similar assertions with respect to pedestrian behavior in marked crosswalks.

Also a study in California, conducted by Willdan Associates for the Department of Public Works of the City of Long Beach in 1986, suggested not installing marked crosswalks (2). Accident reports from 1976 to 1985 were reviewed and information obtained from 3,490 accident reports was also analyzed to summarize accident types and location configurations. This study confirmed that (2) "Marked crosswalks shall not be installed at uncontrolled locations unless a special study by the City Traffic Engineer determines such marking to be necessary and desirable for the specific purpose of encouraging concentration of pedestrians at a certain point."

Later, Stites et al. revisited this issue. Their study, "Evaluation of Marked and Unmarked Crosswalks at Intersections in California" conducted in 1994, examined the safety effects of crosswalk markings based on an analysis of pedestrian crashes at 380 highway intersections in California (3). The pedestrian-related accident rates were calculated using field pedestrian counts and estimated pedestrian daily volumes. One of the remarkable contributions of this study is that it put forward a detailed, multistep study site selection process. As a result, a relatively large sample of intersections throughout California was included. Also, they analyzed three groups of intersections including: (1) all the selected intersections; (2) only those intersections with accidents; (3) intersections with and without signals. Their results showed that pedestrian-related accident rates were higher at marked crosswalks than unmarked crosswalks for the first two conditions (3). Further, the pedestrian crash rates at 380 unsignalized intersections were 2 or 3 times higher in marked than in unmarked crosswalks when expressed as crash rates per unit pedestrian-vehicle volume (3).

This study also pointed out that a key factor in safety performance at marked versus unmarked crosswalks is the degradation in looking behavior and a more aggressive (arrogant) attitude of pedestrians using marked crosswalks. Well-marked crosswalks experience fewer pedestrian violations than poorly marked (worn) crosswalks (3). However, marking crosswalks might result in an increase in rear-end accidents.

It is noted that neither Herms' nor Stites's study presented behavioral data to prove the aggressive attitude of pedestrians using marked crosswalks. They did not determine how the results might be different for two-lane versus multilane roads, or higher ADT versus lower ADT sites.

In 1997, Campbell criticized Herms' and Stites's study methodologies (*17*). He pointed out three concerns. First, Herms' study did not describe how the crosswalks were selected. Second, both studies did not collect any behavioral data to interpret pedestrians' lack of caution which may result in higher crash rates. Third, the study cannot separate the effect on crashes of striping a crosswalk from the pre-existing conditions (infrequent gaps, accident history, speed, intersection design, etc.) that led to the crosswalk being striped (*17*). Campbell's study came to a conclusion that "the accident data do not necessarily indicate anything adverse about pedestrian behavior or any negative effect of the painted crosswalks themselves."

Similarly, in the work of Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians by Thomas et al. focused on an older pedestrian group and pointed out that crosswalk markings appear associated with increased risk of pedestrian-motor vehicle collision to older pedestrians at sites where no signal or stop sign is present to halt traffic. The presence of crosswalk marking was associated with increased risk overall even after controlling the amount of pedestrian traffic, vehicular traffic, and other site characteristics.

Besides the studies mentioned above, there were two before-after studies that indicated marked crosswalks involved higher accident rates. The first one described by Gurnett (5) was a project to remove painted strips from three locations because they had bad crash records. And the crashes indeed decreased after removing the crosswalks. However, Zegeer et al. (8) pointed out that such a result does not show the effect of removing the paint, but are very likely the result of the well-known statistical phenomenon of regression to the mean in their study. The other before-after study was by the Los Angeles, CA, County Road Department in July 1967 (6). They installed painted crosswalks at 89 intersections. As a result, pedestrian crashes increased from 4 to 15. Also, rear-end collisions increased from 31 to 58 after marked crosswalks were added since traffic volume increased. In conclusion, this study showed that more pedestrian crashes happened after painting the crosswalks than before for the sites with ADT above 10,500.

Unmarked Crosswalks

In contrast to the studies described above, several studies reported reduced crashes associated with marked crosswalks. Consequently, conclusions were drawn that unmarked crosswalks actually involved higher crash rates.

In 1983, Tobey et al. conducted a study titled "Pedestrian Trip Making Characteristics and Exposure Measures" for the Federal Highway Administration. The objectives of this project were to identify specific pedestrian trip making characteristics and behavior, develop pedestrian exposure measures, and determine the relative hazardousness of pedestrian behaviors, activities, and various situational factors (*18*). The exposure measures were compared to accident information to determine the relative hazardousness of various pedestrian characteristics and behaviors.

They analyzed factors contributing to pedestrian jeopardy in five regions of the United States: Florida, Maryland, Missouri, New York, and Washington. First, they surveyed the pedestrian behavior at 762 intersections and also obtained the control type and other physical features of the intersections. Then, they sampled pedestrian-vehicular accident records at 495 intersections from the five regions randomly to analyze the pedestrian behaviors and accident locations, as well as the indigenous conditions. Based on the raw data, they calculated the hazard scores involving pedestrian and vehicle exposure, site characteristics, and accidents (8, *18*). The results are contained in Table 2. Each of the factors in the database was analyzed in terms of its hazard score when there were no marked crosswalks and also when all crosswalks were marked.

Table 2 Selected Hazard Scores in Tobey Study (*18*)

CONDITION	HAZARD SCORE
Intersections without signals	+2.0
Intersections without controls	+2.3
Intersections with Stop control	-1.3
Intersections with 4 way stop	-2.1
Intersections with vehicle signal heads	+1.2
Intersections with vehicle and pedestrian signal heads	-2.4
Intersections with marked crosswalks:	
On both streets	-2.4
On one street	+1.0
Intersections without marked crosswalks	+2.5

According to their analysis, scores between -1.3 and +1.3 are considered to be non-significant. Positive scores indicate the behavior or feature is more common in the accident reports than the study intersections, while negative scores are less common (*18*). Thus, their results appeared to favor marked crosswalks over unmarked crosswalks. The differences between the Tobey study and other studies can be explained by the fact that this study considered many factors beyond marked and/or unmarked crosswalks. For instance, they considered functional classification, number of lanes, channelization, parking restrictions, pedestrian accommodations, street lighting, commercial lighting, adjoining land use, intersection type, lane configuration, signalization and marked or unmarked situation. Their study methodology was quite useful for determining pedestrian crash risk for a variety of human and location features. They evaluated crashes at marked and unmarked crosswalks as a function of pedestrian volume multiplied by vehicle volume (*18*). Although this study showed nearly all the marked crosswalks were safer than unmarked crosswalks, there were some exceptions.

In addition, Daly et al. (*19*) discussed the criteria for the installation of pedestrian crossings in England, 1991. This is also a before-after study. The accident rates at sites where no pedestrian crossing facility existed were compared after installing a zebra, pelican or refuge crossing. In this study, 50 “no crossing” sites, similar to the sites where pedestrian crossings were placed, were chosen to obtain an average number for pedestrian/vehicle conflicts. They collected pedestrian flow data before and after the installation of crossing facilities at 57 locations, involving 16 zebra crossings, 19 refuges and 22 pelican crossings. Meanwhile, 3 years of accident data at 204 locations before and after installation of new crossings including 38 zebra crossings, 109 pelican crossings and 57 zebra to pelican crossing conversions were collected (*19*). Afterward, accident frequency models were established based on accident data, site flow and layout characteristics.

Their study results indicated that: (1) a reduction of 18% of total accidents occurred between the 3 year period with before 877 accidents and after 736 accidents at 204 sites where data were collected; (2) pedestrian accidents decreased by 28%, reducing from 371 to 266. To sum up, the introduction of crossing facilities had a positive impact on accident levels. However, this study does not simply focus on analyzing the effectiveness of marking crosswalks.

Comparison of Different Study Results

According to the study results documented above, several earlier researches firmly believed that marked pedestrian crosswalks revealed poor safety performance although fewer studies held the opposite opinion. In a word, there is no clear-cut evidence from reviewed studies to allow us to come to a conclusion whether either marked or unmarked crosswalks are safer. There are also many reasons for the inconsistency.

First of all, the research objectives in studies were diverse. Some involved both signalized and unsignalized intersections, as well as midblock crossing locations. As a result, the pedestrian-related accident rates from those studies did not simply reveal the actual performance of markings at unsignalized intersections. Also, some studies included uncontrolled intersections and many of which had unmarked crosswalks. They did not focus on the identification of the subtle relations among uncontrolled, stop-controlled intersections and marked/unmarked safety performance. Generally, stop-controlled intersections were less hazardous. In addition, the methodological differences might have contributed to the discrepant results. The models or functions used to calculate pedestrian-related crash rates were different in each study. Thus, units of pedestrian crash experience was also inconsistent from one study to another. Also, the selected study type had impact on the study results. For instance, two-lane versus multilane roads, as well as high volume versus low volume at study approaches will produce different results on the safety effects of marked and unmarked crosswalks.

3.3.2 Behavior Studies

In addition to crash-based studies, it is also crucial to review studies pertaining to pedestrian and motorist behaviors at marked and unmarked crosswalks. One of the critical debates with respect to behavioral studies is whether pedestrians have a false sense of security in marked crosswalks that may lead them to be less cautious or more aggressive than in unmarked crosswalks or non-crosswalk locations (*17*). Therefore, recently more studies are focusing on behaviors at such locations to compare the similarities and differences of both pedestrian and driver behaviors. The following paragraphs discuss some of these behavioral studies.

Pedestrian Behavior Studies

It is universally believed that pedestrians have a deep belief that a marked crosswalk is a safety device. Herms first proposed the hypothesis that pedestrians' lack of caution at marked crosswalks lead to the higher rate of crashes (1).

Later, Knoblauch et al. (*13*) conducted three before-after case studies as stated in their project report "Investigation of Exposure Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets and Major Arterials" to clarify this issue. In the first case, four intersections on a roadway were chosen with only one intersection having a marked crosswalk during the study time. They intend to determine the effect of crosswalk markings on pedestrian and driver behavior. For that matter, related data involving vehicle speed and pedestrian behaviors were collected including: (i) vehicle speed with no pedestrian present; (ii) vehicle speed with a pedestrian on the way; (iii) vehicle speed with a pedestrian on the roadside; (iv) pedestrian crossing locations; (v) pedestrian gap seeking behavior. The data was collected for 20 hours before the crosswalks were installed and for a similar period several months after they were installed. Based on the analysis of the results, researchers concluded that very little change occurred in either the vehicular travel speed on average or in the behavior of both motorists and pedestrians between the before and after conditions at all study locations (*13*).

Furthermore, in the similar second case study, they estimated pedestrians' age, gender, looking behavior (e.g., whether there was head movement), length of time in the roadway, direction of travel, and location of the pedestrian in or out of the crosswalk area based on observation. Likewise, they also observed motorists behaviors including vehicle speed, type of vehicle, direction of travel, and pedestrian activity within the driver's observation zone. The results indicated no change in vehicle approach speeds before or after marking the crosswalk. In addition, they found that without the marked crosswalk, some pedestrians crossed the street somewhat diagonally. Thus, marked crosswalks in some level reduced the distance they were exposed to traffic. Also, significantly fewer pedestrians looked during the first half of the crossing after the crosswalk was marked (*13*).

Last but not least, the research team performed a third case study to learn pedestrian and driver behavior using two different types of crosswalk. From this case study, they concluded that apart from marked or unmarked crosswalks, diagonal configuration was recommended. This was also a compared study that involved changing patterns in a midblock crosswalk. The results indicated that pedestrian behavior was affected by different marking types. Namely, more pedestrians (59.2% compared to 47.2%) crossed entirely in the crosswalk and fewer pedestrians (9.0% compared to 3.3%) crossed partially in the crosswalk which came to the conclusion that the diagonal crosswalk is somewhat more effective in attracting pedestrians and retaining them during the entire crossing.

The same conclusions were obtained involving pedestrians' looking behavior. For instance, 39.5% pedestrians did not look and only 4.7% looked prior to and during crossing under the initial crosswalk patterns. However, merely 9.2%, compared to 39.5%, pedestrians did not look and 41.7% (compared to 4.7%) looked prior to and while crossing the changed pattern (*13*). Thus, the diagonal configuration was thought to be somewhat more effective than the parallel lines at guiding pedestrians to use the crosswalk and also resulted in an increase in the number of pedestrians who looked for oncoming traffic prior to and during crossing.

The study by Knoblauch et al. in 2001 also aimed at measuring the effects of crosswalk markings on driver and pedestrian behaviors at uncontrolled intersections (*20*). The study sites include 11 locations in four U.S. cities. All of them are two- or three-lane roads with speed limits of 56 to 64 kilometers per hour or 35 to 40 miles per hour. The behavioral data including pedestrian crossing location, vehicle speed, driver yielding, and pedestrian crossing behavior were observed and collected. Based on the analysis, no evidence was found indicating that pedestrians are less vigilant in a marked crosswalk (*20*). Overall, this study put forward that marked crosswalks at relatively low-speeds and low-volumes in unsignalized intersections was not found to have any measurable negative effects on pedestrian or driver behaviors.

However, Nitzburg and Knoblauch later found that pedestrian searching behavior which was defined as looking left and right for oncoming traffic was actually improved at crossings after they were marked (*21*). Besides the above finding, pedestrian and motorist behaviors in both the first and second half of the crosswalks were compared. Results showed that pedestrians paid more attention while using the second half of midblock crosswalks, forcing the right of way over 15% of the time, compared to about 8% of the time in the first half of the crossing (*21*).

In the field of behavioral studies, a recent prominent study effort was conducted by the Traffic Safety Center at the University of California, Berkeley that addressed pedestrian and driver behavior at uncontrolled locations. They collected extensive driver and pedestrian behavior data at both marked and unmarked crosswalks. The selected study sites in California were with "matched pairs". They explained that "intersections with matched pairs of marked and unmarked crosswalks were considered desirable because most exogenous factors are held constant, allowing a direct comparison between the crosswalks." (*16*, *22*) As a result, pedestrian and driver behaviors within marked and unmarked crosswalk pairs at the same intersection were compared.

In their study conducted in 2007, a focus was made on interpreting pedestrian and driver knowledge of right-of-way laws by identifying potential human factor explanations for the crosswalk dilemma (*16*). Several statistically significant differences in marked versus unmarked crosswalks were identified including, pedestrians and drivers lack in accurate knowledge of right-of-way laws related to marked versus unmarked crosswalks at unsignalized intersections, and pedestrians and drivers exhibit different behaviors in marked versus unmarked crosswalks on multi-lane, higher volume roads.

In their 2008 study, the following issues were addressed.

- Is the age or gender of the pedestrian correlated with his or her behavior? For this matter, they recorded the gender and approximate age of the pedestrian observed.

- Do pedestrians use more, less, or the same amount of caution when crossing at a marked crosswalk as compared with an unmarked crosswalk? For this matter, they recorded pedestrian's "looking behavior" and waiting location (curb or street) when a marked versus an unmarked crosswalk is used.

- Do drivers yield more often to pedestrians in marked crosswalks than unmarked crosswalks? For this matter, they recorded whether the driver yielded when encountering a pedestrian in the crosswalk.

Besides the observation variables, several derived variables explained below were also analyzed for each location which expanded the scope of behavior study (*22*).

- *Average gap acceptance (lanes)*. This variable measures the number of times that no vehicle was present in a lane encountered during a pedestrian's crossing. The maximum number of gaps is equal to the number of lanes across which the crosswalk extends.

- *Average number of immediate yields (drivers).* This variable is the sum of the number of times the first driver encountered by a pedestrian in each lane yielded (as opposed to not yielding and trapping the pedestrian on the curb or within the street).

- *Average vehicle exposure (pedestrians)*. This variable is the sum of the total number of vehicles encountered by a pedestrian during a crossing.

- *Multiple-threat opportunity*. This variable measures for each pedestrian the number of times in which a driver yielded in one lane (the first encountered in the crossing direction) whereas a driver in the adjacent lane of the same direction of travel (the next encountered) did not yield. The incidence of multiple-threat opportunities was applicable only for the crosswalks across the multilane intersections. For the four- and five-lane intersections, two pairs of multiple-threat opportunities were considered, the first set of same-direction lanes encountered in a crossing and the second set.

Their major findings included: (1) pedestrians were likely to be confused regarding right-of-way laws at unmarked crosswalks than marked crosswalks; therefore, pedestrians were more likely to be assertive in unmarked crosswalks, looking both ways before crossing, waiting in the street instead of on the curb before crossing; (2) pedestrians in marked crosswalks were more likely to have drivers immediately yield the right-of-way to them; and a higher rate of yielding in marked crosswalks can actually result in an increased incidence of multiple-threat crashes in both the first and second halves of their crossings (*16*, *22*). The multiple-threat crash scenarios can be explained by a common understanding that when pedestrians are crossing at a marked crosswalk, the first driver from the outer lane may see the pedestrian and make a stop, but the other driver's sight from the inner lane may be blocked due to the first vehicle so as not to stop successfully which creates an accident (*22*). These study results can be applied to two-lane and also multi-lane roads, and yet the differences in marked versus unmarked crosswalks appear more pronounced across several variables for multi-lane roads.

In most cases, pedestrians tend to choose any convenient location to pass through intersections. Compared with signalized intersections, they prefer the flexibility of midblock and unsignalized intersections according to a survey conducted by Sisiopiku and Akin in 2003 (*23*). Moreover, the majority of pedestrians reported that they cross at intersections or within crosswalks most of the time or always. Those who crossed outside the crosswalks claimed that they were in a hurry, and the road was clear, or the nearest crosswalk was too far away (*24*).

Yagil also explained pedestrian compliance with crosswalk laws from the perspective of behavioral biology (*25*). First of all, the health belief model stated that behavior was influenced by cognitive factors, such as cues to action, perceived threats and benefits, and barriers. Secondly, the personal motives include both “instrumental”, for example gains or losses related to compliance, and “normative”, like personal values. Finally, situational factors included the presence and behavior of other pedestrians, mood, and the physical environment. Yagil conducted a survey in Israel and found that normative motives, such as an obligation to obey the law, were the strongest predictor of crossing behavior. In the meanwhile, situational factors, such as high traffic volume, were also influential. Besides, this study pointed out strong differences by gender, namely women’s behavior was more motivated by perceived danger and the social environment, while men’s behavior was more influenced by the physical environment.

Driver Behavior Studies

Traffic safety researchers have long argued that driver behaviors outweigh physical elements as a cause of motor vehicle collisions (*16*). Studies with respect to driver behavior are fewer than pedestrian behavior study. In general, public tends to believe drivers often fail to yield to pedestrians at both marked and unmarked crosswalks (8).

As Knoblauch et al. stated in their report, little difference in the average vehicle speeds between two different marking types (i.e. marked and unmarked midblock crossings in the third case study) was found. Thus, they draw the conclusion that the type of crossing had no significant effect on motorist behavior (*13, 26*). Further, Knoblauch et al.'s 2001 study confirmed that marking a crosswalk had no effect on driver yielding (*20*). But they found a slight reduction in speed by drivers approaching a pedestrian in a marked crosswalk compared with a crossing that is unmarked.

Later, Nitzburg and Knoblauch (*21*) indicated that there existed significant differences in drivers' behavior between daytime and nighttime. Meanwhile, there were also differences in both driver and pedestrian behaviors when the pedestrian was in the second half of the crosswalk compared with the first half. Over 40% drivers yielded to pedestrians in the high-visibility crosswalks, 20% yielded to pedestrians in a marked midblock crossing location, and less than 3% yielded to pedestrians in an unmarked crosswalk during day time (*21*). However, at night, only 25% yielded in the high-visibility crosswalks and 17% in the marked midblock crossings. They also found that when pedestrians were in the second half of the crosswalk compared to the first half, there were differences for both pedestrians' and drivers' behavior. This is an issue that other studies did not address before. The results indicated that over 11% of drivers chose to yield to pedestrians in the second half of a crosswalk, but no drivers yielded in the first half at unmarked crosswalks. Likewise, at marked midblock crossing locations, 54% of drivers yielded in the second half while 6% yielded in the first half.

According to Nasar's observation in 2003 (*27*), many drivers ignored pedestrians in crosswalks and they either sped up or swerved to pass them. When a pedestrian was in the crosswalk, 43% of drivers did not stop. But they did not mention whether those crosswalks were marked or unmarked. The study by the University of California at

Berkeley in 2007 filled the gap and found that drivers do yield more frequently to pedestrians in marked crosswalks compared with unmarked crosswalks.

The drivers' survey conducted in Virginia (*24*) suggested that over 80% of respondents "always" or "most of the time" yielded to pedestrians in a midblock crosswalk, although less than 64% responded that they always yield to pedestrians when making a left turn. Nonetheless, Varhelyi's study in 1996 (*28*) was about driver behavior at a non-signalized zebra crossing which was diagrammed in the paper as a crosswalk marked by a series of broad horizontal stripes, usually called a "continental" or "ladder" crosswalk. It found that 73% of the vehicles maintained or even increased their speed, and only 27% of them slowed down as required. But a separate survey indicated that 67% of the motorists say they "always" or "very often" slow down. This case illustrated that there existed a difference between observed and stated behaviors.

From the study by Sisiopiku and Akin (*23*), it can be seen that pedestrians held a different perception of driver behaviors. Less than half of the respondents stated that drivers typically yield to pedestrians in designated locations. In the meanwhile, half said that drivers turning on red do not yield to pedestrians crossing on green.

In summary, it can be seen that the results of behavior studies vary greatly. Both pedestrians and drivers prefer more convenient and faster travel. However, whether the crosswalks themselves cause both pedestrians' and drivers' aggressive behaviors their lack of vigilance is not evident. Additionally, for both pedestrians and drivers, the behaviors and understanding of right-of-way laws appear to be inconsistent.

3.4 Knowledge of Crosswalk Laws

Several previous studies not only focused on comparing pedestrian and driver behaviors at marked and unmarked crosswalks, but also studied their understanding of right-of-way laws at such locations to interpret the differences between behaviors. Pedestrian's misunderstanding of right-of-way laws lies in the situation that they are unaware that motorists must legally yield the right-of-way when they are crossing in unmarked as well as marked crosswalks since experiences have taught them that drivers are not likely to yield.

The terminology "Right-of-way" is defined in Nevada Revised Statutes (NRS) as (7):

> *"Right-of-way means the right of one vehicle or pedestrian to proceed in a lawful manner in preference to another vehicle or pedestrian approaching under such circumstances of direction, speed and proximity as to give rise to danger of collision unless one grants precedence to the other."*

Additionally, Chapter 484B of NRS has laws designed to minimize traffic accidents involving pedestrians (7).

> *"Drivers should always give pedestrians the right-of-way in crosswalks without traffic controls.*
>
> *Pedestrians, however, should not walk off the curb and into an intersection in the way of a vehicle if it is waiting for a pedestrian to cross.*
>
> *Pedestrians crossing roads at places other than crosswalks should always give right-of-way to any approaching vehicles."*

The duties of motor vehicle drivers to pedestrian (7):

- *Exercise due care to avoid a collision with a pedestrian;*
- *Give an audible warning with the horn of the vehicle if appropriate and when necessary to avoid such a collision; and*

- *Exercise proper caution upon observing a pedestrian on or near a highway, street or road or in or near a school crossing zone marked in accordance with NRS 484B.363 or a marked or unmarked crosswalk.*

In general, study results indicated that both pedestrians and drivers have a limited perception of crosswalk right-of-way laws (*23*, *24*, *29*,*30*, *31*).

Tidwell and Doyle (*29*) pointed out majority of the people understand that pedestrians must cross at signals or crosswalks, and that turning drivers must yield to pedestrians in the crosswalk at intersections. The Uniform Vehicle Code (UVC) requires motorists to stop or slow down only for pedestrians already in a crosswalk. However, almost 70% of respondents thought motorists were required to stop or slow down for pedestrians waiting on the curb at a marked crosswalk. The researchers recommended that there is a need for pedestrian safety education programs, explanatory signs on pedestrian signals, and enforcement of pedestrian right-of-way laws.

Another study by Sisiopiku and Akin (*23*) in 2003 indicated that over half of the pedestrian participants thought motorists should yield to pedestrians only at designated crosswalks. However, there was no definition for “designated crosswalks” in their report and they also pointed out some extreme understandings. Nearly one third of participants said that pedestrians should always have the right-of-way and seven percent of them said motorists should always have the right-of-way. Nevertheless, for this study, the participants were asked about when they thought vehicles should yield to pedestrians but the results did not reveal pedestrians’ understanding of right-of-way laws.

Then, in the survey of drivers in Virginia conducted by Martinez and Porter in 2004 (*24*), most respondents, nearly 75% to 92%, were aware of the law that they should yield in midblock crosswalks and stop before crosswalks at signals. In spite of this, over half incorrectly thought that pedestrians have the right-of-way all the time, even when they cross outside of intersections or crosswalks.

Similarly, a survey conducted in 2004 by Sarkar and Andreas in San Diego, California (*30*), indicated that many respondents were not aware of traffic laws with respect to pedestrian's duties and rights. In the meantime, the analysis results of driver participants showed that they were insensitive to pedestrian-driver conflict situations.

A remarkable research conducted by the University of California at Berkeley (*16*) completed a study on pedestrian and driver's knowledge regarding right-of-way laws. In their study, a series of focus groups of pedestrians and drivers, as well as a sample of unsignalized high volume, multi-lane intersections were involved. Generally, they figured out that pedestrians and drivers lack an accurate knowledge of right-of-way laws related to marked versus unmarked crosswalks at unsignalized intersections. Also, they utilized the key findings of understanding in right-of-way laws to partially explain the observed differences in crash risk in marked versus unmarked crosswalks on certain multi-lane roadways.

Drivers who encounter pedestrians in unmarked crosswalks were less likely to yield which is partially due to the lack of knowledge of the pedestrian's right-of-way within unmarked crosswalks. Fortunately, this misunderstanding resulted in reduced crashes in unmarked crosswalks which were explained partially by differences found in pedestrian behavior in such locations. That is, pedestrians often appear to exhibit higher caution while crossing unmarked crosswalks. But one cannot help wonder what reasons lead pedestrians to behave like this. As a circular argument, this behavior can be explained as pedestrians do not know whether they have the same legal right-of-way while crossing unmarked crosswalks. For most of the time, they walk through based on their own experiences which show that drivers are not likely to yield.

The same theory can also explain why pedestrians exhibit less caution when crossing a marked crosswalk. At marked crosswalks, some drivers lack the knowledge of right-of-way laws. Mainly they do not understand their responsibility to stop for pedestrians. More seriously, some drivers know the law but still fail to yield. Hence, in marked crosswalks, drivers' yielding behavior does not always occur, and pedestrians show less caution at such locations resulting in higher rate of crashes in marked crosswalks.

In summary, the misunderstanding or lack of accurate knowledge of right-of-way laws at unsignalized pedestrian crosswalks can be connected with a higher crash risk at pedestrian crosswalks. As Meghan and David (*32*) stated, "a lack of knowledge of right-of-way suggests a significant pedestrian safety concern and opportunities for improvement." Although knowledge of the right-of-way law does not certainly result in compliance, the lack of knowledge would most likely not result in improved yield behavior – especially in the case of multi-lane roads.

3.5 Countermeasures

Over the years, there have been numerous evaluations and promotions on countermeasures to improve pedestrian safety in crosswalks. The ITE Informational Report (*33*) listed 25 treatments to enhance safety at uncontrolled pedestrian crossings, including automated detection, curb extensions, flags, flashing beacons, in-roadway signs, marked/legends and etc. In general, previous studies indicated that these countermeasures will play an active role in improving safety performance in crosswalks.

The study by Fitzpatrick, K. et al. at the Texas Transportation Institute is one of the evaluation studies that expanded the scope beyond just examining marked versus unmarked crosswalks (*15*). They evaluated the effectiveness of many other pedestrian safety countermeasures for uncontrolled crossings, including marked crosswalks;

enhanced high-visibility, or “active when present” traffic control devices; red signal flasher or beacon devices; and conventional traffic signal.

Earlier, Van Houten and Malenfant (*34*) found that a succession of countermeasures would result in a large increase in the percentage of drivers yielding to pedestrians. Additionally, they found that adding signs, stop lines, and pedestrian-activated lights increased the percentage of drivers stopping by up to 50% and substantially reduced the number of conflicts (**Error! Bookmark not defined.**). Likewise, Knoblauch (*26*) studied the effectiveness of high visibility crosswalks with ladder striping, overhead lighting and signage. The results also showed that these countermeasures have positive effect on drivers yielding. Besides, no increase in pedestrian aggressiveness, running, or vehicle-pedestrian conflicts was found compared to unmarked control crosswalks.

Apart from physical countermeasures, social marketing approaches may also be effective in improving pedestrian safety. For example, Nasar studied the effectiveness of hand-held signs to prompt drivers to stop for pedestrians in a crosswalk. A significant increase in stopping was found, both at the treatment crosswalk and at a downstream non-treatment crosswalk (*27*). However, the long-term effects of this approach were not evaluated in this study.

Since pedestrian and driver behaviors play an important role in the safety performance at marked and unmarked unsignalized intersections, behavioral countermeasures may be needed for enhancing safety as recommended by Meghan and David (*32*). However, they did not introduce detailed information pertaining to behavioral countermeasures.

Over the last few decades, the combination of engineering, education, and enforcement countermeasures, often referred to as the “3-Es of Safety”, have been in the middle of discussion. In the study by UC Berkeley in 2007, “3-E” strategic measures to mitigate crash risk for marked crosswalks at multi-lane, high volume locations were recommended (8, *16*, *22*). It was noted that additional funding should be allocated to evaluate engineering countermeasures. It is better to obtain a full inventory of "at risk" marked crosswalks and prioritize the crosswalks for countermeasure installation based on exposure-adjusted crash risk, and select appropriate countermeasures from the NCHRP/TCRP guidelines.

In addition to marking crosswalks and other engineering countermeasures, education and enforcement are other ways to enhance pedestrian safety at unsignalized intersections. Almost all of the studies evaluating the education countermeasure have shown positive effects on pedestrian safety (3, *35*). In those studies, children have been tested to the greatest extent and have performed remarkably well when instructed about pedestrian safety. However, more studies need to be done on whether or not this positive effect will stay with the child. In addition, more studies need to be conducted to determine the effects of education on adults and young adults concerning pedestrian safety (3).When pertaining to studies involving enforcement to improve pedestrian safety, it was found that there are gaps in the results. Britt et al. (*36*) conducted an evaluation for a public education and enforcement program in Seattle in 1995. After that, they suggested that "a very high level of enforcement is necessary to achieve even minor or temporary changes in driver behavior and that environmental and behavioral factors may be more influential than enforcement".

David and Meghan (*16*) recommended that engineering and education countermeasures can be strengthened by increasing enforcement of right-of-way laws at marked and unmarked crosswalks. Moreover, targeting both drivers and pedestrians with fines and warnings can provide additional funding to enable sustained enforcement efforts.

3.6 Summary and Conclusions

The literature review provided a comprehensive review of studies related to controversial discussions, guidelines and safety performances of marked and unmarked pedestrian crosswalks in the U.S. and other countries. Crosswalk marking is a useful traffic control device, but it is very important for the public to realize the positive as well as the negative consequences of marking crosswalks.

From the mobility point of view, marked crosswalks appears to increase pedestrian mobility, but with perhaps a deceived sense of security. In fact, most studies previously conducted indicated more pedestrian crashes at marked crosswalks than unmarked crosswalks. It is believed that such results vary by location and by jurisdiction. These inconsistencies in the literature about the safety merits of marking crosswalks indeed put transportation agencies and the public into a dilemma. Thus, state officials and agencies prefer to develop guidelines to direct installation of marked crosswalks based on the basic guidelines in the MUTCD.

A specific set of guidelines can help engineers make sound decisions for the placement of marked crosswalks. Several layouts of guidelines have been accepted by the majority of practicing traffic engineers. In general, the layouts incorporate key elements such as pedestrian and traffic volumes, pedestrian demographics, location and availability of other treatment types and vehicle speed. Since most states and cities tend to make their own guidelines, there is no uniformity among them. Hence, new guidelines can be established, based on the general guideline layout documented in the literature, for conditions in Nevada.

As can be seen from the safety performance of marked and unmarked crosswalks presented in the report, some studies indicate a need to reduce the use of marked crosswalks while others indicated the opposite. There is no clear-cut evidence to conclude whether marked or unmarked crosswalks are safer, thus the decision will be quite tough. The reasons of these differences include the diverse research objectives, methodologies, and study sites. A nationwide study in 2001 confirmed and refined what smaller, localized studies have observed for more than thirty years: marked crosswalks across multi-lane roads (roads with 3 or more lanes) with travel volumes exceeding 10,000 average daily traffic (ADT) present a higher crash risk for pedestrians compared to unmarked crossings. This provides a general idea regarding under what condition marked crosswalks are more dangerous. However, collection of local data is needed for Nevada, to help provide the answers to these questions.

Additionally, there are controversies with respect to pedestrian and driver behaviors at marked and unmarked crosswalks. Discussions are launched around pedestrian's caution at two types of crosswalks as well as driver's yielding behavior. The differences between behaviors at these two types of crosswalks can be explained by the understanding of right-of-way laws. Generally, both pedestrian and drivers lack accurate understanding of right-of-way laws and that is why they are exhibited differently at such locations. Thus, understanding how pedestrians and drivers interpret right-of-way laws and their behaviors will help elucidate the differences between pedestrian-related accident rates at marked and unmarked crosswalks.

To conclude, the review of the literature suggests that engineers and planners should carefully balance the benefits and risks of crosswalk treatments. More specific research needs to be conducted so as to interpret the impasse of crosswalk markings.

4 SAFETY PERFORMANCE IN NEVADA

This portion of the report is going to explore the safety performance of marked crosswalks versus unmarked ones at unsignalized intersections in Nevada. Major data collection involving site selection and data acquisition was conducted towards further analysis.

On one hand, a large number of study sites were selected so that a sufficient sample size was available for conducting valid statistical analyses. Site selection was a multi-level process, with each level focusing on eliminating potential issues and biases caused by specific factors. For example, sites to be selected must have the following characteristics: (i) at least 3-year crash records; (ii) not within school zones which might influence the assessment; (iii) availability of AADT from either past studies or agency counting stations. The sites will be limited to two major urban areas: Las Vegas and Reno-Sparks-Carson City.

On the other hand, data acquisition involves collecting pedestrian-related crash data, and traffic and pedestrian exposure data. Vehicular traffic volumes and crash records were provided by NDOT. Nevertheless, pedestrian volumes were counted manually in the field. A minimum of one day was spent at each site; however, the pedestrian daily demands that will be used to calculate pedestrian crash rates were estimated based on the field counts. Further, pedestrian-related crash rates were computed and compared in marked and unmarked crosswalks. And statistical tests were applied to test statistical significance of the difference between crash rates in marked and unmarked crosswalks. Last but not least, the crash rates were compared with previous studies conducted in other states to determine whether Nevada's data is consistent with other states.

4.1 Selection of Study Intersections

The primary purpose of site selection is to provide sufficient study objects for the safety performance analysis. The selection process is constitutive of three phases, each of which has specific screening criterion. The selection of study intersections starts from “high pedestrian crash” areas, which are associated with concentrated representative locations for the safety performance assessment. Several states and local agencies are trying to identify “high crash” areas to extract problem areas and figure out the improving countermeasures. This study applies an approach using a geocoding algorithm to attach crash information with Google Maps, and then abstract the high crash areas. A certain amount of unsignalized intersections can be picked up from high pedestrian crash areas.

PHASE I—Identify Crash Locations in Nevada

In this study, the pedestrian-related crash data from 2007 to 2010 in Nevada are pulled from the NDOT database. Crash frequency is to be considered as the solely criterion at the very beginning. After the first screening, 3500 crash data entries (with 2279 recorded at marked crosswalks and 1221 at unmarked crosswalks) in the 4-year period were then embedded in Google Maps as shown below using a geocoding algorithm based application developed by the research team.

Figure 2 presents the pedestrian-related crash records (shown as Red Dots) in the State of Nevada. It can be seen that the majority of crashes occurred within the pre-defined study areas, i.e. Las Vegas and Reno-Sparks-Carson City areas. Approximate 60% of the overall crashes were recorded in the Las Vegas area. In the Reno-Sparks area, most of the accidents occurred in the City of Reno although the numbers of marked crosswalks are nearly equal in Reno and Sparks. While zooming in the maps, detailed information concerning crash location, crash day and hour, and injury type etc. can be obtained. When the crash location could be identified through Google Maps, further search was conducted to confirm the specific location in order to obtain all valuable crash information. It should be noted that the reason why a certain amount of locations cannot be identified lies in the data quality which has been an on-going issue for many states and local jurisdictions.

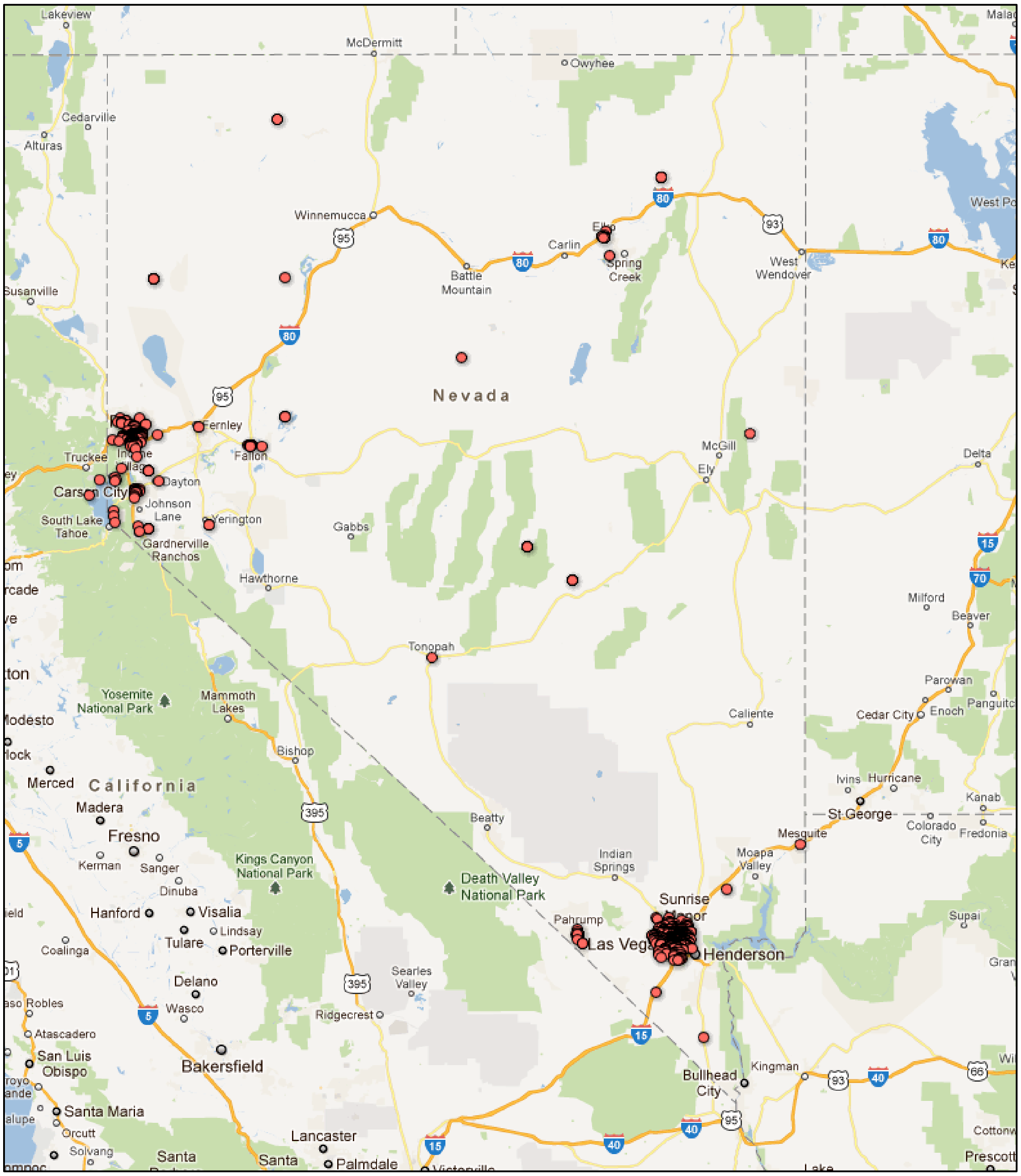

Figure 2 Four-year Pedestrian-related Crash Record in Nevada

For this study, the 3500 intersections were refined by removing locations with wrong names, wrong traffic control devices and wrong study areas. At the end of this phase, a total of 1460 unsignalized locations with detailed crash records were selected to establish the candidate study sites database. The other 2040 unsignalized locations were negligible because the crash records were not comprehensive, as shown in Table 3. For instance, several records only had street names without any other information to identify the specific location of the accident. Even so, 1460 locations are adequate for further screening and analysis.

Table 3 Breakdown of Intersection Identification

Filter Criterion	Number of Deleted Intersections
Initial Number of Intersections	3500
Wrong Location Name	951
Wrong Traffic Control Devices	439
Suburban Locations	334
Mid-block	316
Total	2040

PHASE II—Identifying High Pedestrian Crash Areas

“High crash” areas are normally identified as areas having traffic related problems such as speed. In this study, “high crash” areas are associated directly with pedestrian-related crashes. The higher the number of crashes, the more serious the safety concern is. By distinguishing crosswalk types in high crash areas, the safety performance assessment for each type can be measured.

The crash records in Figure 2 can be pulled out with detailed information on the maps below. It is not only easy to figure out the basic information, such as crash year and injured status, but also to visualize the high crash areas and locations since the crash frequency at one location can be obtained by counting the red dots at that location. For example, at the W 1st Street and Ralston Street Intersection in Reno, there are two red dots recording two pedestrian-related crashes. Therefore, high crash areas can be identified roughly by visualizing and counting the number of crashes shown on the maps.

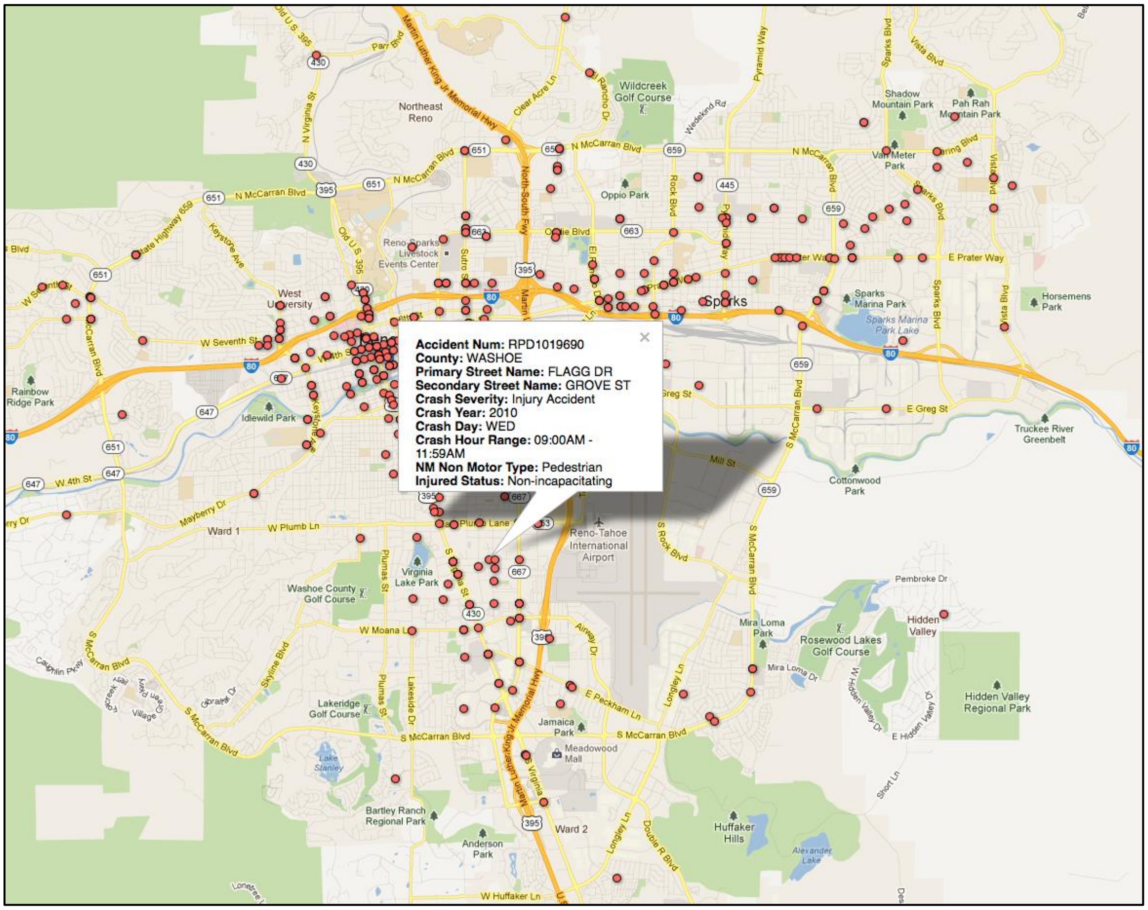

Figure 3 Pedestrian-related Crash Record in the Reno-Sparks Area

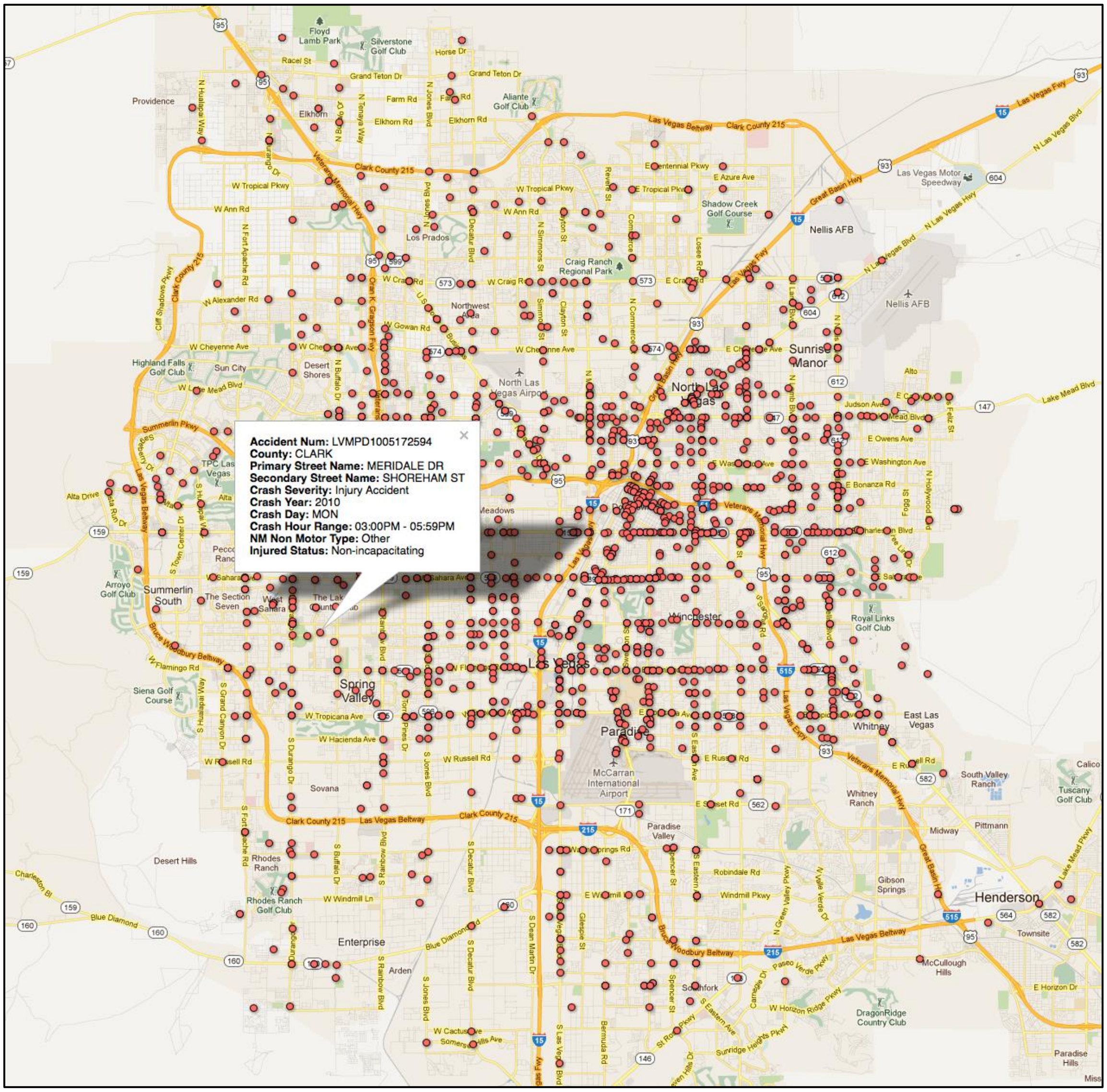

Figure 4 Pedestrian-related Crash Record in the Las Vegas Area

To summarize, high pedestrian crash areas consisted of: (i) Reno downtown area; (ii) Northeastern region of Sparks; (iii) Areas along Carson Street in Carson City; (iv) Las Vegas downtown area as shown below. Among 1460 unsignalized candidate study sites, 580 intersections were ultimately embraced in the identified high crash areas. They were sorted afterwards for further screening and data collection.

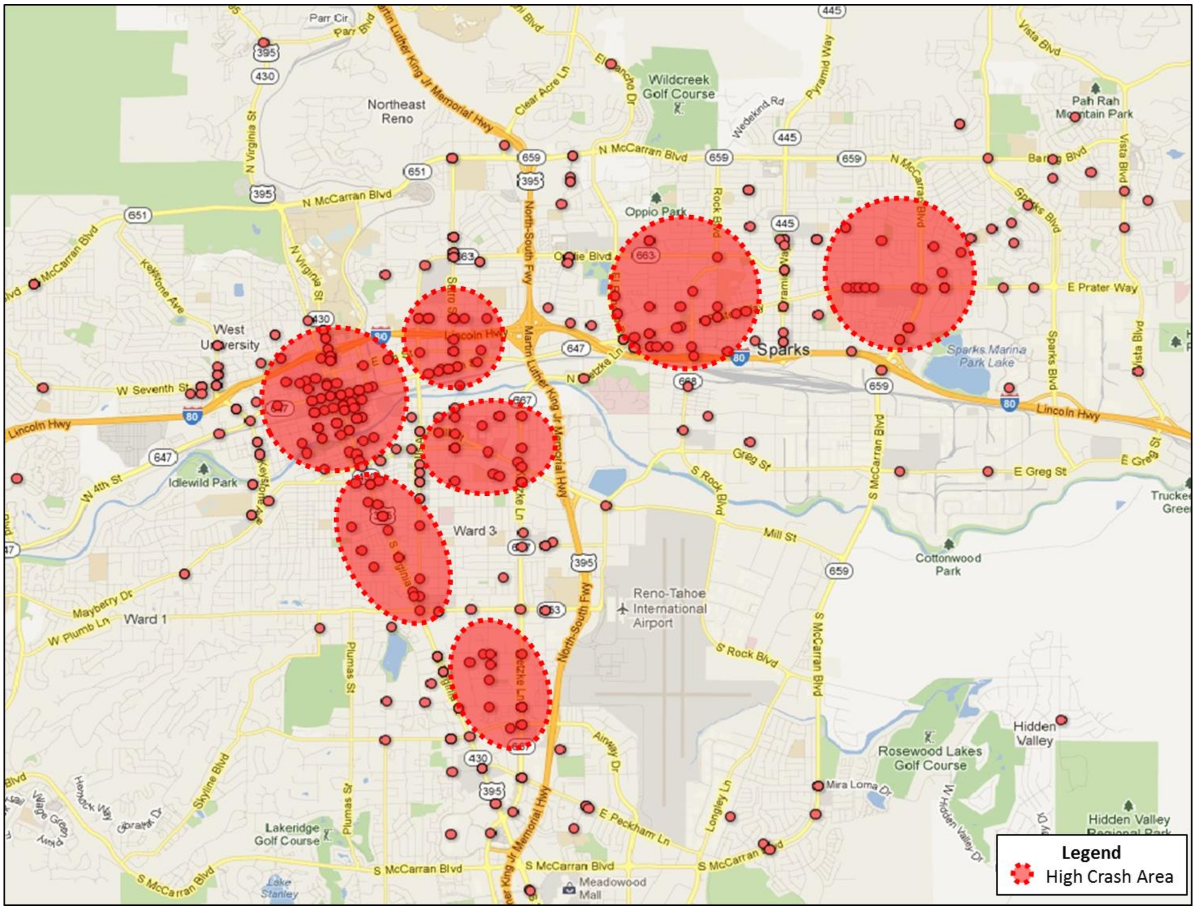

Figure 5 High Crash Areas in the Reno-Sparks Area

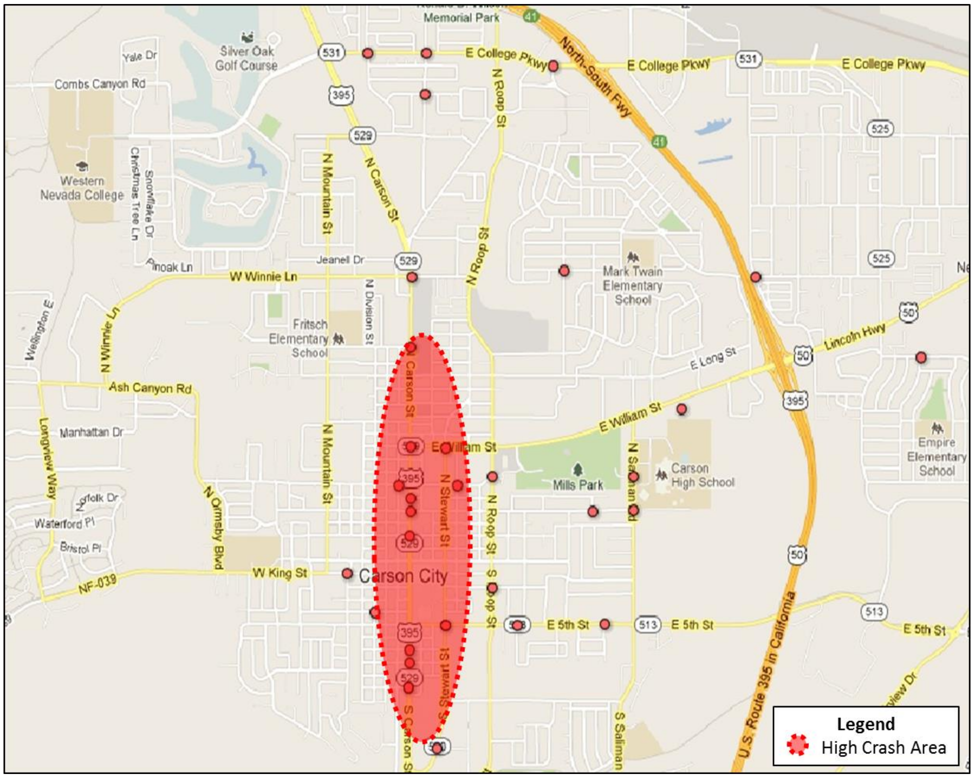

Figure 6 High Crash Areas in the Carson City Area

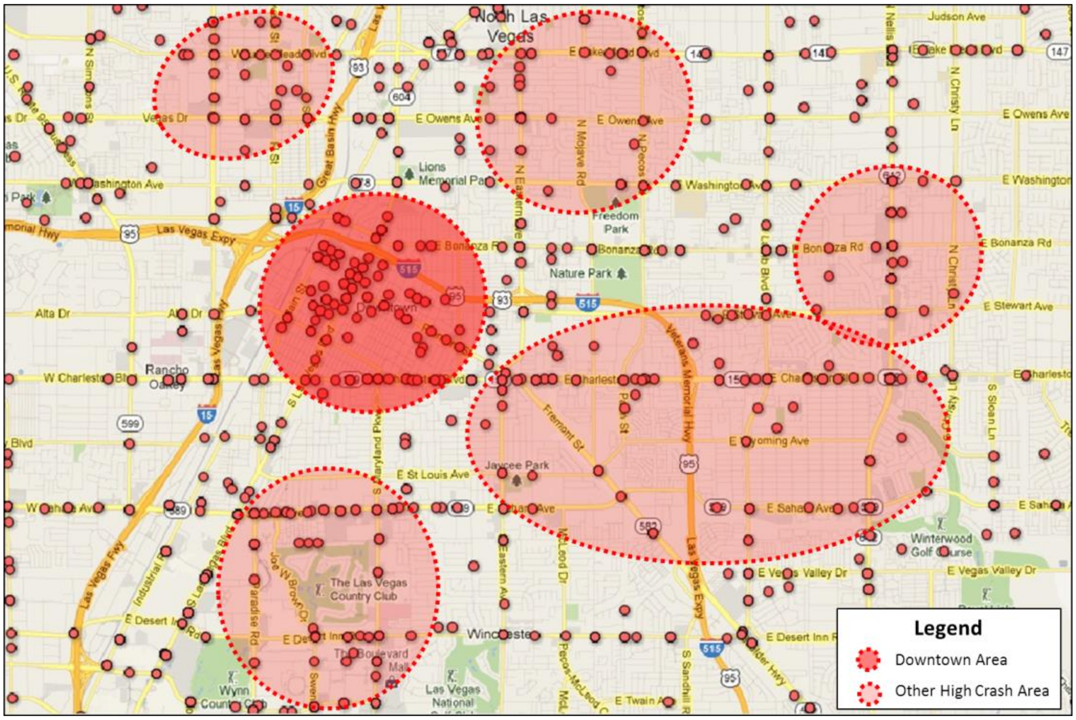

Figure 7 High Crash Areas in the Las Vegas Area

PHASE III—Study Site Selection

By ranking the crash frequencies, high crash locations were identified in each study area. A further task was to select study sites that satisfy the basic requirements for this study, including availability of AADT, a balanced number of T-intersections and Four-leg intersections. The availability of pedestrian ADT was another critical consideration while selecting study intersections. Therefore, among the 580 unsignalized candidate sites, a total of 129 intersections were selected as the final study sites. Considering the availability of data, the number of study intersections in each study area was decided and is shown below.

Table 4 Number of Selected Study Sites in Each Study Area

Study Area	Number of Selected Sites
Reno-Sparks	70
Carson City	10
Las Vegas and Henderson	49
Total	129

4.2 Data Collection

The purpose of data collection was to retrieve sufficient intersection information in order to analyze the safety performance of marked and unmarked crosswalks. The data collection effort involved costly travel to various sites in Nevada and some uncertainty existed as to specific analysis needs. Three phases were involved in the data collection process. The first phase involved the basic characteristics of study sites. The second phase consisted of vehicular volume and pedestrian volume counting. And the third phase was concerned with the detailed pedestrian-related crash data. Consequently, a database involving all needed data was constructed to accommodate information for further analysis.

PHASE I—Intersection Information

Basic intersection information such as location and geometry layout was identified. To be specific, the location of each study site was identified using county, city, name of major streets and name of minor streets. The geometry layout of the intersections was identified through Google Maps. Other substantial intersection information includes:

- Intersection Control Devices, such as Two-way Stop-controlled (TWSC), All-way Stop-controlled (AWSC), or Uncontrolled;
- Number of Vehicle Travel Lanes on Major Street, such as 2-lane in each direction or 4-lane on both direction. The number of travel lanes on either two approaches or each approach needed to be specified. Also, the number of through, left-turn, and right-turn lanes in all directions were recorded;
- Crosswalk Information, such as with or without crosswalk and existing crosswalk types were recorded. The current crosswalk condition should be identified in detail. If there was a marked crosswalk at the study site, the width of the crosswalk was measured during the visit to the study site. Crosswalk information, if noted, was to be collected on all approaches;
- Land Use Pattern Around, which included residential or commercial land use, as well as whether there is a bus stop nearby etc.;
- Site Geometry Characteristics. For example, whether it is a T-intersection or an angled T-intersection were recorded. Also, the sight distance was measured at the same time.

PHASE II—Vehicular and Pedestrian Volume Counting

In order to calculate pedestrian-related crash rates at two types of crosswalks, the vehicular and pedestrian exposure were required. The vehicular traffic volumes were obtained from the NDOT website. The average daily traffic (ADT) was obtained for each study intersection. For some intersections without volume information, a proper interpolation between post miles was performed. Nevertheless, pedestrian volumes could not be obtained from other resources and field counting was necessary. The City of Henderson provided several pedestrian ADTs at unsignalized locations based on previous studies. Actual field counting was conducted in other study areas.

A 24-hour pedestrian counting period was conducted at signalized intersections near the selected unsignalized study intersections using a Digital Video Recorder (DVR) settled into the signal cabinet. An assumption was made here that the pedestrian volume distribution at the selected unsignalized intersection had the same pattern as the nearby-signalized intersection. The distance between these two locations should be less than 1000 feet. The 24-hour pedestrian volume distributions at several locations in Reno are demonstrated in Figure 8.

Further, the corresponding pedestrian volumes reduced to the percent of 24-hour counts by hour were obtained to decide on the number of hours to count at nearby unsignalized locations. It can be seen from the 24-hour counting that the pedestrian peak hours were during 10:00AM--12:00PM and 3:00PM--6:00PM. Therefore, a 3-hour counting period of pedestrians from 3:00PM to 6:00PM at selected unsignalized locations was performed using video cameras setup in each location. The 3-hour counting period was subdivided into 15-minute intervals. In the counting period, only those pedestrians that were crossing within the crosswalk lines or within 5.0 feet of those lines at the intersection were counted. For those locations without marked crosswalks, an extension of the sidewalk was used to determine the width of the unmarked crosswalks. Afterwards, the 3-hour volumes were converted into estimated pedestrian ADTs based on the percentage distribution. Ultimately, pedestrian ADTs at 54 selected intersections were obtained.

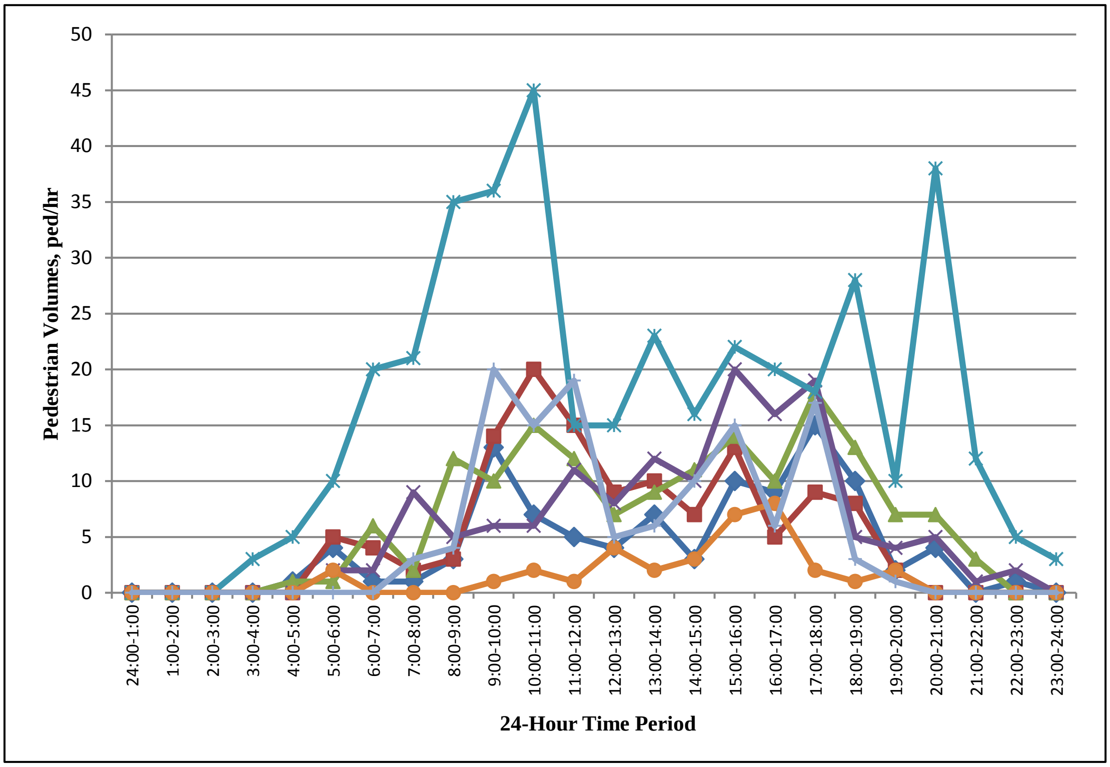

Figure 8 Pedestrian ADTs at Selected Signalized Intersections

PHASE III—Pedestrian-related Crash Data

The third phase consisted of crash data in Nevada. The pedestrian-related crash data from 2007 to 2012 was pulled from the NDOT safety database. This dataset is the same one that was used to identify high pedestrian crash areas in the previous section. Initially, 3878 distinct crash data was provided including pedestrians' actions, location and factors, primary and secondary streets documented at the time of the crash. However, not all of the crash data was integrated and further filtration was necessary. The corresponding crash information of the selected 129 unsignalized study sites is included.

The crash data shows that the total fatal pedestrian crashes occurring in the selected 129 intersections were two times in marked crosswalks compared with unmarked crosswalks. The overall pedestrian crashes, including fatal and injury, occurring in marked crosswalks were also twice as much as those in unmarked crosswalks. The data analysis subset and respective results are described in detail in the following section.

4.3 Data Analysis

4.3.1 Pedestrian ADT Estimation

Since only 54 study sites had actual pedestrian and vehicular volume data, the data at other locations needed to be estimated. The basic goal was to develop a model capable of predicting pedestrian volumes based on known volumes and selected intersection characteristics. A linear regression model was generated for the estimation.

Two separate prediction models were considered at the beginning. For both models, the standardized residuals were stored to check the basic assumptions of the linear regression model. In the first model, the intersection's characteristics and population of the county where the intersection is located were considered as independent variables. The known pedestrian volume was treated as the dependent variable. A linear regression was established using Minitab Software with a significance level of 0.05. However, the coefficient of determination R^2 of the linear regression model is relatively small ($R^2 = 0.355$) and based on the interpretation of p-values of the model, the linear model cannot be used to explain the existing data.

On the other hand, a similar linear regression model was established using speed limit, vehicular ADT and population as independent variables. The pedestrian volumes remain the dependent variable. Initially, three variables were involved in the model but only speed limit and vehicular ADT variables were significantly related to the response variable which is the pedestrian volume. In this model, the coefficient of determination R^2 of the linear regression model is relatively adequate ($R^2 = 0.82632$).

Therefore, the ultimate linear regression model to estimate pedestrian ADT involves variables of speed limit and vehicular ADT. The detailed model results are shown below.

$$Estimated\ Pedestrian\ ADT = \beta_0 + \beta_1 \times VOLUME + \beta_2 \times SPEED\ LIMIT = 291.88 + 0.09801VOLUME - 7.022SPEED\ LIMIT \quad (1)$$

Where, $\beta_0 = 291.88$; $\beta_1 = 0.09801$; $\beta_2 = -7.022$ according to the output from Minitab Software.

Table 5 Linear Regression Model Parameters

Predictor	*Coef*	*SE Coef*	*T*	*P*
Constant	291.88	36.38	8.02	0.000
VOLUME	0.09801	0.04109	2.39	0.021
SPEED LIMIT	-7.022	1.307	-5.37	0.000
R-Sq=83.0%				

The generated linear regression model was applied to the rest 75 (54 out of 129) study sites to calculate the pedestrian ADT.

4.3.2 Analysis of Safety Performance

An overall analysis was conducted in this section to compare the safety performance of the two types of crosswalks. The selected 129 unsignalized intersections with 5-year period crash records were involved. The basic contents include: (i) number of observations of marked and unmarked crosswalks; (ii) average pedestrian-related crash rates in marked and unmarked crosswalks; (iii) significance test of the results.

It should be noted that the observed rate is thought of as an estimation of the true underlying rate. The number of crashes at both types of crosswalks varies by chance, depending on pedestrian exposure, traffic volumes and the probability of the crash. Therefore, the statistical significance of the difference between crash rates at marked crosswalks and unmarked crosswalks was tested. If the test result indicates the two crash rates are significantly different, there is a 95% (assuming the test for significance at the 95% confidence level) probability that the crash rate at the marked crosswalks is either higher or lower than the unmarked crosswalks. Conversely, there is only a 5% probability that the difference between crash rates at marked and unmarked crosswalks is due to chance or random error.

In each study area, both computed crash rates at marked and unmarked crosswalks are based on less than 100 observations. Tests for statistical significance are performed to determine the probability that the differences between rates were the result of chance using confidence intervals as the criterion. If the confidence intervals overlap, the difference is not statistically significant at the 95% significance level. But if they do not overlap, the difference is statistically significant (*37*). The 95% Confidence Intervals (CI) for crash rates based on less than 100 events are generated using the following equations and values in Appendix I.

$$Lower\ Limit\ of\ CI = R \times L\ ;\ Upper\ Limit\ of\ CI = R \times U \tag{2}$$

Where,

R—pedestrian-related crash rate at marked/unmarked crosswalks;

L—the value of L in Appendix I that corresponds to the number N in the numerator of the rate;

U—the value of U in Appendix I that corresponds to the number N in the numerator of the rate;

Further, pedestrian-related crash rates were calculated using the following equation.

$$Pedestrian - related\ Crash\ Rate\ at\ Marked\ or\ Unmarked\ Locations =$$

$$\frac{Number\ of\ Pedestrian-related\ Accidents}{Pedestrian\ ADT \times Entering\ Vehicle\ ADT}\ (acc./(ped. \cdot million\ entering\ veh.)) \tag{3}$$

Table 6 Pedestrian-related Crash Rate

Study Area	Observations	Average Pedestrian-related Crash Rate		Confidence Interval ($\times 10^{-8}$)		Significance
		Marked	Unmarked	Marked	Unmarked	
Reno-Sparks	70	7.63E-08	3.73E-08	(5.5865, 10.1779)	(2.3871, 5.5435)	Yes
Carson City	10	1.75E-08	2.37E-08	(0.5687, 4.0873)	(0.7701, 5.5348)	No
Las Vegas and Henderson	49	7.92E-08	3.26E-08	(5.4845, 11.0668)	(1.8301, 5.3932)	Yes
Overall	129	7.42E-08	3.05E-08	(5.9350, 9.1636)	(2.2073, 4.1083)	Yes

In the Reno-Sparks area, the crash rate of marked crosswalks is higher than unmarked crosswalk and the confidence intervals do not overlap which indicates that the pedestrian-related crash rate in marked crosswalks is significantly higher than unmarked crosswalk. Similarly, the result in the Las Vegas and Henderson area shows that the marked crosswalk does have a higher pedestrian-related crash rate since the difference is statistically significant. The comparison of two different crash rates in two major areas in Nevada yields similar results. However, in Carson City the difference between crash rates is not significant. The overall data in Nevada indicates that the crash rate in marked crosswalks is approximate 2.5 times the crash rate in unmarked crosswalks.

4.4 Summary and Conclusions

The major effort of this section is analyzing the safety performance of marked and unmarked crosswalks. Currently, Nevada has relatively balanced marked and unmarked crosswalks. However, the safety performance of these two types of crosswalks is different according to this study.

Initially, basic study sites selection from extensive unsignalized intersection databases was conducted. Three-phase screening was applied, with the first two phases used to identify high pedestrian crash areas and the last phase to label specific study sites. This was done by placing all the required data on Google Maps using a geocoding algorithm. The fact that this is a creative and adaptable approach to display crash data should be pointed out. In the end, 129 unsignalized intersections were selected for safety assessment.

Table 7 Number of Selected Intersections after Each Phase

Site Selection	Screening Criterion	Number
Initial Entry Data	NDOT Crash Record	3500
Phase I	Identify All Crash Locations	1460
Phase II	Identify High Crash Areas	580
Phase III	Identify Study Site based on Data Availability	129

Table 8 Number of Selected Intersections in Each Area

Study Area	Initial Number	Number of Selected Intersections after Each Phase		
		Phase I	Phase II	Phase III
Reno-Sparks	1342	795	230	70
Carson City	102	59	15	10
Las Vegas and Henderson	2056	606	335	49
Total	3500	1460	580	129

The safety assessment shows that marked crosswalks in the Reno-Sparks and Las Vegas areas involved higher crash rates than unmarked crosswalks. And the crash rates in these two areas comprise higher crash rates than the Carson City area. The overall comparison of Nevada data indicates consistent results with several studies indicating that marked crosswalks do involve higher crash rates than unmarked locations.

Therefore, the decision of marking a crosswalk is more enigmatic when the safety intent is not fully fulfilled. Simply from the safety performance point of view, unmarked crosswalks are doing better than marked crosswalks in Nevada; however, marked crosswalks do have advantages such as directing pedestrians across complex intersections, warning drivers, and enforcing pedestrian crossing regulations etc. Hence, the decision making of which crosswalk type to use is complicated and needs elaborate balancing of both safety and mobility factors.

5 GUIDELINE DEVELOPMENT

Based on the descriptions in the MUTCD and the safety analysis in Nevada, a statewide guidance for determining pedestrian crosswalk types is developed in this section. The guideline is mainly a decision making assistance tool which involves a descriptive statement for general locations and a mathematical calculation engine named Mark/Unmark Choice Tool.

At first, a conceptual framework of the guideline, inspired by existing warrants in Nevada, was developed. The intent was to design a cognitive process resulting in the selection of crosswalk types among alternatives, i.e. mark and unmark. Key elements for determining crosswalk types like speed limit, volume and intersection geometry and their vast number of combinations played an important role in developing the numerical portion of the guideline. The Mark/Unmark Choice Tool, as the core of the guideline, is based on a combination of PROMETHEE and the Analytical Hierarchy Process (AHP) multi-criteria decision analysis methodologies. A ranking score considering all the potential factors, including variables such as volume, speed limit, and pedestrian related crash records etc. was produced to represent the likelihood of using a certain type of crosswalk. Furthermore, the proposed guideline was compared with FHWA guidelines in a case study involving field data in the State of Nevada.

5.1 Statewide Agency Survey

Before developing the guideline, a statewide agency survey was conducted to gather information regarding current practices in Nevada. This section documents the survey results from several agencies in Nevada regarding their policies on marking pedestrian crosswalks at unsignalized intersections. The findings from the survey will serve as supporting and guiding materials for developing a statewide guideline.

The survey questionnaire (attached in Appendix II) was sent to the following agencies in March 2011: Clark County, City of Las Vegas, City of North Las Vegas, City of Henderson, City of Reno, City of Sparks, and Carson City. Feedback was received from five agencies in April and May 2011. In general, agencies within Nevada are applying some basic internal guidelines while deciding whether to mark their crosswalks. However, some of the guidelines or policies are not documented or not in detail. Most agencies indicated that a statewide guideline would be helpful for promoting uniformity in application of pedestrian crosswalk markings.

5.1.1 Existing Guideline and Warrants

Currently, Clark County, the City of Las Vegas, City of North Las Vegas and City of Reno have basic guidelines with respect to crosswalk markings. In which, the City of Las Vegas and City of Reno have documented guidelines, but other agencies do not have a published policy. The responses from agencies are summarized below.

Clark County

Clark County uses 20 pedestrians per hour as the determination to install a marked crosswalk. The 20 pedestrians per hour benchmark was developed based on engineering judgment. However, they do not think this guideline is sufficient.

City of Las Vegas

The City of Las Vegas follows the general guideline outlined in the Manual on Uniform Traffic Control Devices (MUTCD). In summary, the guidelines they follow indicate that crosswalks at intersections should be marked if: (1) there is substantial conflict between vehicle and pedestrian movements; (2) significant pedestrian concentrations occur; (3) pedestrians could not otherwise recognize the proper place to cross; and (4) traffic movements are controlled.

City of North Las Vegas

The City of North Las Vegas has generic guidelines, but they do not have specific documented warrants. In general, as a matter of policy and practice, they normally avoid marking crosswalks with the exception of signalized intersections, intersections warranting school crossing guards, trail crossings, and other high pedestrian activity locations.

City of Reno

The corresponding policy set up by the City of Reno is quoted as a "Point System" which is similar to the method documented in the previous research study "Evaluation of Marked and Unmarked Crosswalks at Intersections in California". This policy excludes school crosswalks and signalized intersections. They point out that the purpose of a marked crosswalk is to indicate a preferred route of travel when crossing either a street or a complex intersection. Therefore, the purpose of this policy is to establish minimum criteria for the installation of marked crosswalks to provide the greatest possible benefit to both pedestrians and motorists.

In the system, the total points are 30. Three aspects including pedestrian volume, general conditions, and gap time should be scored. In order to be considered for a marked crosswalk, a location must be rated to at least 16 points within the Point System. The first consideration is pedestrian volume. The total number of pedestrians crossing the street during peak pedestrian hours is divided into six categories with corresponding scores from 0 to 10. Marked crosswalks will not be installed where the pedestrian volume is 10 or less. Furthermore, five general conditions are scored from 0 to 10. Those basic conditions include whether the installation will clarify and define pedestrian routes, channelize pedestrians into a significantly shorter path, position pedestrians to be seen better by motorists, expose pedestrian to fewer vehicles and etc. Last but not least, the average number of gaps per every 5-minute period should be scored. That is the number of unimpeded vehicle time gaps equal to or exceeding the required pedestrian crossing time in an average 5-minute period during peak vehicle hour.

In addition, the location must also meet three basic conditions: (1) crosswalk markings will not be installed where the pedestrian volume is less than 10 pedestrians per hour during peak pedestrian hours; (2) crosswalk markings will not be installed on roadways where the 85th percentile speed exceeds 40 mph; and (3) crosswalk markings will not be installed unless the motorist has an unrestricted view of all pedestrians at the proposed crosswalk location, for a distance not less than 200 feet approaching from each direction. Locations with restrictive views will require special attention.

Carson City

The policy regarding crosswalk markings followed by Carson City is contained in the Carson City Municipal Code Title 18, Appendix Division 12, "TRANSPORTATION, STREETS AND TRAFFIC". However, they stated that while the guidelines are limited, there has been no need expressed to update or improve them. They suggested that additional guidelines could be useful for consistency and to defend why or why not crosswalks were installed.

5.1.2 Issues with Existing Guideline

In general, the City of Las Vegas and City of Reno have not met serious issues while applying their guidelines. They provide detailed information in their responses. However, Clark County does not think the 20 pedestrian per hour benchmark is sufficient. This benchmark was developed based on engineering judgment; and it is not a known published policy.. They suggest it would be helpful if there are studies that can back-up the criteria. Most agencies indicated a statewide guideline would be helpful in promoting uniformity in application of pedestrian crosswalk markings.

5.1.3 Key Impact Factors

Agencies were asked to suggest considerable factors influencing their decision to install crosswalks. Eight common factors, such as traffic volume, speed limit, geometric layout, and pedestrian volume etc. are listed as multiple choices.

Both Clark County and Carson City indicated the listed potential considerations for crosswalk implementation are valid and could be used to develop warrants. Clark County supplemented that adjacent land uses which may provide higher pedestrian generation and the proximity of crosswalks within the areas should be considered.

The City of North Las Vegas suggested the consideration of pedestrian volumes and geometric layouts of intersections while setting up guidelines for crosswalk marking. To be specific, pedestrian volumes should be considered as a primary factor but only in conjunction with other measures to control traffic. Additionally, pedestrian accident occurrence should not be a consideration in determining the need for a marked crosswalk without the consideration of active remediation for causal factors. Merely marking a crosswalk could easily increase pedestrian accidents. Moreover, the geometric layout of intersections should be a consideration to the extent that more complex intersection geometries are not conductive to safe pedestrian crossings with or without marked crosswalks.

They also pointed out that crosswalk markings alone do not provide any form of "protection" for pedestrians from careless driver. A frequent complaint from citizens is that drivers do not comply with NRS requirements to stop for pedestrians in crosswalks whether marked or unmarked.

Based on the survey results documented above, it can be seen that agencies within Nevada are currently executing several crosswalk marking guidelines which are either documented or unwritten rules. These existing policies will be extremely representative and provide a significant reference to generate a statewide pragmatic guideline. Besides, agencies recommended that comprehensive and various factors should be put forward. Such multiple decisive parameters, pedestrian volumes, intersection geometric layout, pedestrian accident occurrence and etc. should be considered while developing the guidelines.

5.2 Statewide Guideline Development

Deciding a pedestrian crosswalk type is quite complex especially when there is no clear-cut evidence to conclude that either marked or unmarked crosswalks are adequate. Different states and agencies prefer to conduct engineering studies to decide whether marking is needed or not. These current studies are blind to some level because of two reasons. On one hand, there are a lot of flaws with the data regarding pedestrian crash. For instance, there was a relatively high percentage of crashes were not reported. Some crash records were not in detail due to subjective reasons. Without a well-laid foundation, an analysis will be futile no matter how well it is performed. On the other hand, the existing guidelines are either qualitative statements or mostly rely on a single dominant factor like pedestrian volume. Such guidelines lack a balanced consideration of all the potential factors, such as pedestrian-related crash records, intersection geometry characteristics and vehicle speed; therefore, the decision process is biased at some locations.

Another issue would be how to evaluate the impact of each potential factor in the decision process synthetically. It can be seen that determining a pedestrian crosswalk type is a systematic process involving intricate decision rules especially when both mobility and safety factors are cogitated altogether. Since those potential impact factors have different categories and criteria, the crosswalk type decision-making process can be considered a typical multi-criteria analysis problem. Accordingly, the perplexed nature of the crosswalk issue can be understood comprehensively. In our daily lives, the multiple criteria are usually weighed implicitly and we are comfortable with the consequences of such decisions that are made based on only intuition. On the other hand, when the issue of safety is involved, such subjective attitudes must be abandoned. It is important to properly structure the problem and explicitly evaluate multi-criteria since pedestrians are deeply affected from the consequences. Therefore, this study attempts to complement the blindness and come up with a more applicable guidance.

5.2.1 Guideline Development

Initially, a conceptual guideline was developed to improve the existing delineations pertaining to the installation of marked crosswalks. To be specific,

- Marked crosswalks must be installed carefully and selectively to guide pedestrians and warn vehicle drivers.
- Marked crosswalks must be installed after an engineering study confirms that the location is suitable for crosswalk marking.
- Marked crosswalks can be selected as a candidate at locations where,
    - There is substantial conflict between vehicular and pedestrian movements, such as downtown and commercial areas. Field observation and data collection are compulsory.
    - There is a need to guide pedestrians considering the geometry layout of the intersection, such as wide intersections or pedestrian concentration, such as at loading islands.

- There is an unrestricted view of all pedestrians at all proposed crosswalk locations, for a distance not less than 200 feet approaching from each direction. Locations with restrictive views will require special attention.
- The location satisfies one of the specific parameter thresholds including (i) the vehicular speed limit is less than 40 mph; (ii) the distance to a nearby crosswalk is more than 200 feet; (iii) the vehicle ADT is less than 15,000.

Additionally, crosswalk markings should not be used indiscriminately and an engineering study should be performed before they are installed. The study should include field observation and corresponding data collection for further analysis. To conclude, given a specific unsignalized intersection, the above guidance will help judge whether this location can be seen as a candidate location for crosswalk markings. If not, unmarked crosswalks would be the clear choice. For candidate locations, a Mark/Unmark Choice Tool assisting the conceptual guideline was developed for the final decision.

In accordance with discussions in the previous section, determining a pedestrian crosswalk type can be considered as a typical multi-criteria decision problem involving alternatives Mark and Unmark crosswalk types as well as several multi-criteria decisive variables. Consequently, an essential idea of the choice tool is put forward as,

$$D\{Mark, Unmark\} = \prod Function[\lambda_i^x + \lambda_j^y + \cdots + \lambda_k^z] \tag{4}$$

In this definition, the *Function* can be defined as linear or non-linear according to the nature of correlation between the response, Mark/Unmark, and explanatory factors like volume, speed limit and intersection geometry etc. demonstrated as $\left[\lambda_i^x + \lambda_j^y + \cdots + \lambda_k^z, i = 1,2, \cdots I; j = 1,2, \cdots J; k = 1,2, \cdots K\right]$. The primary goal is to attain a decision through the combination of all possible factors simultaneously. The details with respect to the development of the choice tool are presented next.

5.2.2 Mark/Unmark Choice Tool

The Mark/Unmark Choice Tool as the core of the guideline comprises three subsections: Input Multi-Criteria Description as the input interface, Calculation Procedure containing inner analysis of response and explanatory factors, and the ultimate Output Results providing the final preference decision. The framework of the guideline is demonstrated in Figure 9. The principles and implementations of the developed guideline are discussed below.

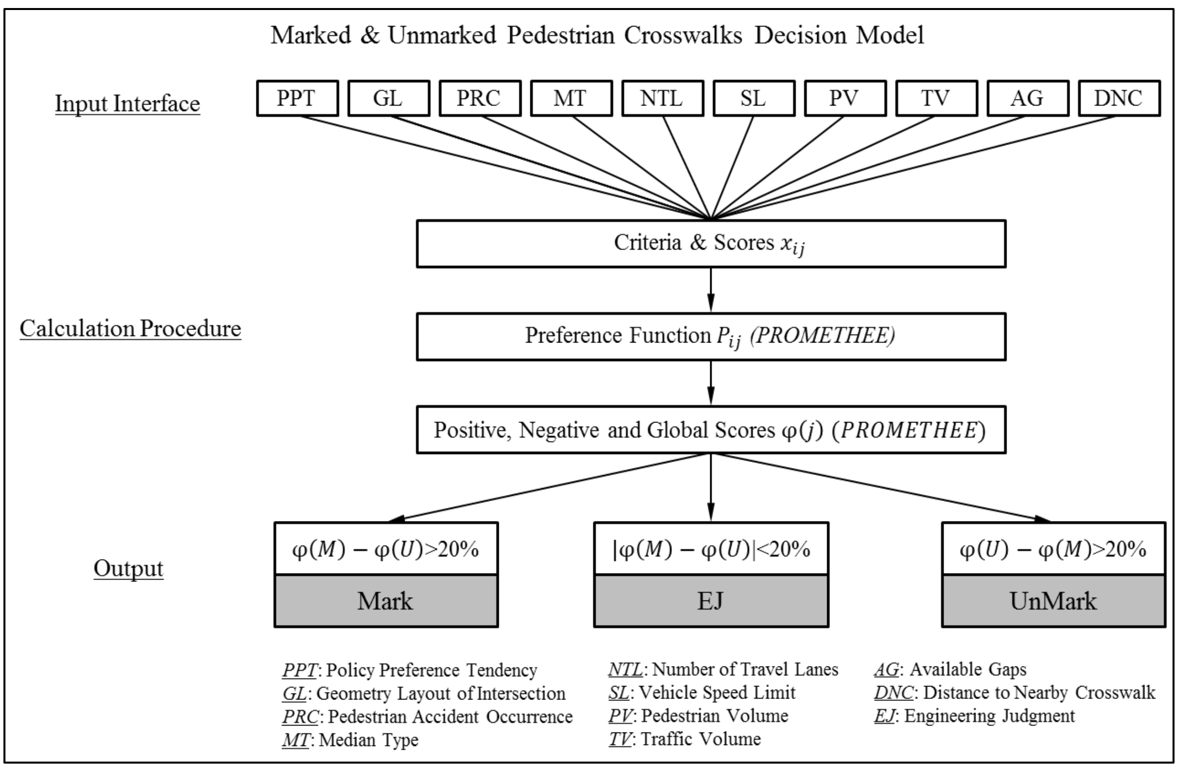

Figure 9 Flow Chart of Developed Mark/Unmark Choice Tool

The development of the Mark/Unmark Choice Tool consists of the following consecutive five processes.

Step 1: Identify factors and generate sub-decision matrices for each factor with respect to each alternative.

The explanatory factors were obtained from previous literature and a comprehensive statewide agency survey in Nevada. As discussed previously, most responses claim that pedestrian volume and speed limit are the major factors followed by the crash record and number of travel lanes. Also, some engineers agree that the policy preference tendency regarding pedestrian crosswalks may be different for different jurisdictions. Therefore, a policy preference factor should also be included in the guidance. The related factors and their attributes are discussed further in Table 9.

Table 9 Key Factors for Determining Crosswalk Type

Key Factor	*Attribute Description*
Vehicle Speed Limit	Vehicle speed affects pedestrians' safety in a number of different ways. According to the Federal Highway Administration's Pedestrian and Bicycle Information Center, faster speeds increase the likelihood of a pedestrian being hit. Further, according to the Federal Highway Administration's Pedestrian Facilities Users Guide: Providing Safety and Mobility (2002), if a pedestrian is hit by a vehicle traveling at 40mph, he/she has a 15% chance of survival, but if the vehicle is going 30mph, chance of survival increases to 55%. Lastly, according to the federal report Improving Pedestrian Safety at Unsiganlized Crossings reviewed previously, states that motorist compliance with yielding to pedestrians in crosswalks is significantly improved by reducing vehicle speed to below 35mph. Therefore, speed limit can be seen as a negative influence factor for consideration of installing a marked crosswalk since under high speed limit circumstances, one would not want to encourage pedestrians to cross for the sake of safety.
Pedestrian Volume	According to the survey results, pedestrian volume is one of the critical factors concerned. At unsignalized intersections, the driver shall yield the

	right of way, slow down or stop if needed to pedestrians crossing the roadway within a crosswalk when the pedestrian is upon half of the roadway upon which the vehicle is traveling, or when the pedestrian is approaching so closely from the opposite half of the roadway as to be in danger. But at unsignalized locations with high pedestrian volumes, crossing pedestrians may severely limit turns and cause intersection back-ups. Therefore, when the crossing pedestrian volumes are relatively high, for instance more than 20 pedestrians per hour, a marked crosswalk should be provided to guide them and also warn the drivers.
Pedestrian-related Crash Record	From the safety point of view, pedestrian crosswalks are supposed to guide pedestrians and also warn vehicle drivers. However, according to the conclusions drawn based on Nevada crash data, marked crosswalks actually involve higher crash rates.. Hence, pedestrian-related crash records should have special attention while deciding the installation of marked crosswalks. If a site with severe crash records does not have a marked crosswalk, then the installation of a marked crosswalk should be considered in order to provide a guide path for pedestrians. But, if a site with sever crash records already has marked crosswalks, other effective countermeasures such as flashing beacons and in-roadway signs should be considered.
Available Gaps on Major Street	At unsiganlized intersections, while the time or distance between two following vehicles is enough, it gives pedestrians who intend to cross an available gap to pass through safely. The City of Reno is executing a point system involving average number of available gaps in 5-minute periods. That is the number of unimpeded vehicle time gaps equal to or exceeding the required pedestrian crossing time. Consequently, in a site with a higher number of available gaps it relatively easier for pedestrians to choose a gap and pass through. In this case, unmarking the crosswalk would have a higher preference than a marked crosswalk.
Distance to Nearby Crosswalks	The distance to a nearby crosswalk is another factor to consider for the installation of marked crosswalks. If the site is within a short distance of

	another marked crosswalk or a signalized intersection, it is not preferable to mark this crosswalk to encourage pedestrians to cross at the other site. This type of unsignalized intersection is pretty common in Nevada. Thus, when the distance between the study site and its nearby crosswalk is within a relatively short threshold, say 200 feet, a marked crosswalk is not preferred.
Policy Preference Tendency Factor	Not only has previous research pointed out that the decision of crosswalk types at unsignalized locations is relatively subjective because of its flexibility and distinctiveness. Thus, a human factor or in engineering studies the engineer judgment factor should be combined with other objective ones. According to a statewide agency survey, the engineering interpretation of guidelines or warrants is significant. In this study, the policy preference tendency factor is put forward to demonstrate this interpretation of developed guidelines. Three categories are provided concerning conservative, aggressive, as well as moderate preference tendency pertaining to crosswalk types. It is believed that in real engineering applications the moderate and conservative policy attitudes are preferred even though aggressive attitudes are also considered.

Besides the factors listed in Table 9, detailed geometry of a study site, traffic volume, and number of vehicle travel lanes as well as median type should also be evaluated while developing the guideline. As a result, ten factors are identified including Policy Preference Tendency (PPT), Geometry Layout of Intersection (GL), Pedestrian Accident Occurrence (PRC), Median Type (MT), Number of Travel Lanes (NTL), Vehicle Speed Limit (SL), Pedestrian Volumes (PV), Traffic Volumes (TV), Available Gaps (AG) and Distance to Nearby Crosswalk (DNC) in the very first input interface section. These factors as input variables are described in the light of abbreviation and properties respectively.

Table 10 Input Variables

Variables		*Abbreviation*	*Evaluation*
C1	Policy Preference Tendency	PPT	1-Conservative, 2-Moderate, 3-Aggressive
C2	Geometry Layout of Intersection	GL	3-Legs, 4-Legs
C3	Pedestrian Accident Occurrence	PRC	Pedestrian related Accidents, acc./yr
C4	Median Type	MT	0-No, 1-Yes
C5	Number of Travel Lanes	NTL	1-Lane, 2-Lanes, 3-Lanes and so forth
C6	Vehicle Speed limit	SL	mph
C7	Pedestrian Volumes	PV	peds/hour
C8	Traffic Volumes	TV	vph
C9	Available Gaps	AG	sec. Average Available Gaps
C10	Distance to Nearby Crosswalk	DNC	feet. Short Distance: less than 500 feet

Additionally, ten variables and their scores g_{ij} to different criteria under mark versus unmark circumstances are generated and therefore the decision matrix is formed as well. Following the basic idea of multi-criteria analysis, the PROMETHEE method starts with the decision tables, with scores g_{ij} need not necessarily be normalized or transformed into a common dimensionless scale. Each factor was scored a value between 0 and 10. For the sake of simplicity, the assumption is made that a higher score value means better preference for alternatives. In practice, a score of 10 suggests that a certain type of crosswalk is absolutely needed. For instance, the factor policy preference tendency is considered in the first place. Three categories are given to this factor as 1-Conservative, 2-Moderate and 3-Aggressive. The conservative policy preference tendency means marking is a preferred choice in this study since it satisfies the ground needs to guide pedestrians. Therefore, the score 10 is assigned from conservative policy preference factors to mark crosswalks since it is the certain choice. On the contrary, the aggressive tendency indicates that unmark is a preferred choice because it is believed that marking is not necessary at the study site. Consequently, a score of 10 is assigned from aggressive judgment to unmarked crosswalks although engineers would not often prefer the risky attitude.

Table 11 Criteria and Scores of Factors

PPT	*1*	*2*	*3*						
M	10.00	5.00	0.00						
U	0.00	5.00	10.00						
M-U	10.00	0.00	-10.00						
U-M	-10.00	0.00	10.00						
GL	*4-Leg*	*3-Leg*							
M	6.42	7.42							
U	3.58	2.58							
M-U	2.84	4.84							
U-M	-2.84	-4.84							
PRC	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
M	9.50	9.50	8.50	8.00	7.75	7.30	6.75	5.00	2.75
U	0.50	0.50	1.50	2.00	2.25	2.70	3.25	5.00	7.25
M-U	9.00	9.00	7.00	6.00	5.50	4.60	3.50	0.00	-4.50
U-M	-9.00	-9.00	-7.00	-6.00	-5.50	-4.60	-3.50	0.00	4.50
MT	*No*	*Yes*							
M	7.30	2.70							
U	2.70	7.30							
M-U	4.60	-4.60							
U-M	-4.60	4.60							
NTL	*6*	*5*	*4*	*3*	*2*	*1*			
M	9.00	8.56	7.63	7.12	2.88	2.50			
U	1.00	1.44	2.37	2.88	7.12	7.50			
M-U	8.00	7.12	5.26	4.24	-4.24	-5.00			
U-M	-8.00	-7.12	-5.26	-4.24	4.24	5.00			
SL	*55*	*45*	*35*	*25*	*15*				
M	0.00	0.00	5.00	7.99	8.50				
U	10.00	10.00	5.00	2.01	1.50				
M-U	-10.00	-10.00	0.00	5.98	7.00				
U-M	10.00	10.00	0.00	-5.98	-7.00				
PV	*40+*	*40*	*30*	*25*	*20*	*15*	*10*	*5*	
M	9.25	8.85	8.50	7.58	7.25	3.00	2.75	1.50	
U	0.75	1.15	1.50	2.42	2.75	7.00	7.25	8.50	
M-U	8.50	7.70	7.00	5.16	4.50	-4.00	-4.50	-7.00	
U-M	-8.50	-7.70	-7.00	-5.16	-4.50	4.00	4.50	7.00	
TV	*500+*	*500*	*400*	*300*	*200*	*100*	*50*		
M	9.00	8.00	7.50	7.25	7.00	6.75	2.50		
U	1.00	2.00	2.50	2.75	3.00	3.25	7.50		
M-U	8.00	6.00	5.00	4.50	4.00	3.50	-5.00		
U-M	-8.00	-6.00	-5.00	-4.50	-4.00	-3.50	5.00		
AG	*12*	*5.5*	*4*	*<4*					
M	9.25	7.65	5.00	2.30					
U	0.75	2.35	5.00	7.70					
M-U	8.50	5.30	0.00	-5.40					
U-M	-8.50	-5.30	0.00	5.40					

DNC	*1000+*	*750*	*500*	*250*	*200*
M	9.00	7.25	5.00	2.75	1.00
U	1.00	2.75	5.00	7.25	9.00
M-U	8.00	4.50	0.00	-4.50	-8.00
U-M	-8.00	-4.50	0.00	4.50	8.00

Note: M-Mark, U-Unmark; M-U/U-M: difference between scores.

Step 2: Determine factor weights.

After establishing the decision matrices for each factor, the relative importance of each factor should be identified. The importance is represented by the assigned weights for factors. This study chose the AHP pair wise comparison method to obtain weights w_i for each criterion C_i. The evaluation of each pair is based on the results from the nationwide survey. The detailed calculation procedure is documented in Appendix III.

Step 3: Determine preference function and preference degrees.

In order to take the deviations and scales of the criteria into account, a preference function is associated to each criterion. This study defines the preference function as $P(M, U)$ to represent the degree of the preference of alternative $Mark$ over $Unmark$ crosswalk type with respect to criterion C_i. A revised linear threshold function is utilized similar to Type 5 in Appendix IV. The function is defined by Equations 5-7 and the curve is demonstrated in Figure 10. It can be seen from the figure that the preference of each alternative is assigned between 0 and 1. When the preference difference between two alternatives is relatively small, e.g. less than a predetermined threshold, there is no significant difference existing in the preference process. Equally, if the judging difference passes a predetermined strict threshold, the preference is absolute. Otherwise, the preference will follow a linear function $F(d)$ with a slope of $1/(p-q)$. For this study, considering the preference degree is following a normalized form, the meaning of preference value is explicitly explained in Table 12.

$$P(M, U) = F\{d_i(M, U)\}, 0 \leq P(M, U) \leq 1, i = 1,2, \cdots n \tag{5}$$

$$d_i(M,U) = g_i(M) - g_i(U), i = 1,2,\cdots n \tag{6}$$

$$F(d) = \begin{cases} 0 & d \le q \\ \frac{d-q}{p-q} & q < d \le p \\ 1 & d > p \end{cases} \tag{7}$$

Table 12 Meaning of Preference Function

Preference Function	*Meaning*
$P_i(M,U) = 0$	No preference or difference between mark and unmarked
$P_i(M,U) \approx 0$	Weak preference for marking
$P_i(M,U) \approx 1$	Strong preference of marking
$P_i(M,U) = 1$	Strict preference of marking
$P_i(U,M) = 0$	No preference or difference between mark and unmarked
$P_i(U,M) \approx 0$	Weak preference for unmarking
$P_i(U,M) \approx 1$	Strong preference of unmarking
$P_i(U,M) = 1$	Strict preference of unmarking

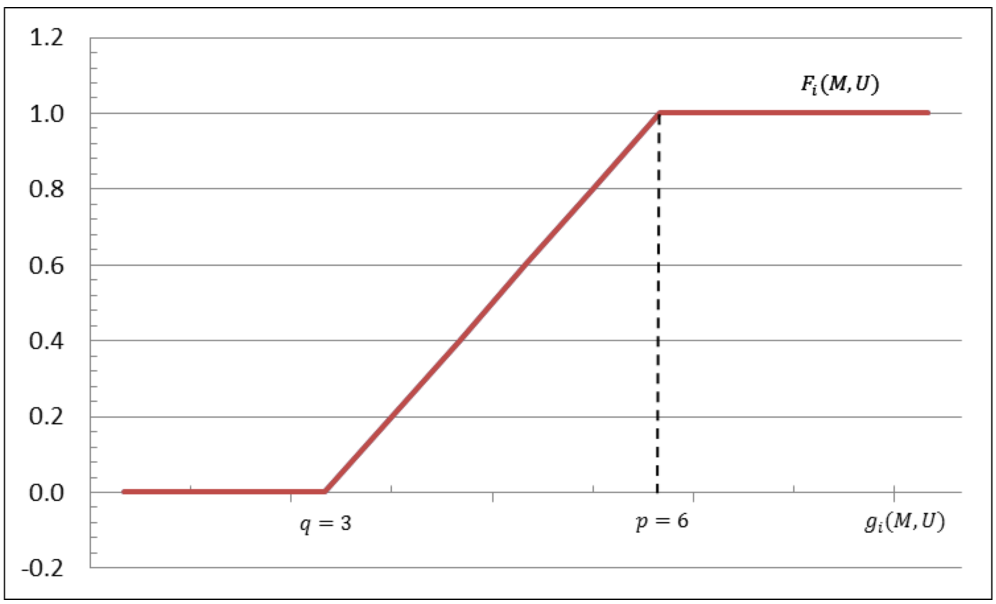

Figure 10 Plot of Preference Function F (d)

Based on the criteria & scores from Tables 11, the preference function is established and the preference degrees are shown in Table 13.

Table 13 Preference Degree of Each Factor against Alternatives

PPT	*1*	*2*	*3*						
$P_1(M,U)$	1.00	0.00	0.00						
$P_1(U,M)$	0.00	0.00	1.00						
GL	*4L*	*3L*							
$P_2(M,U)$	0.00	0.61							
$P_2(U,M)$	0.00	0.00							
PRC	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
$P_3(M,U)$	1.00	1.00	1.00	1.00	0.83	0.53	0.17	0.00	0.00
$P_3(U,M)$	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.50
MT	*N*	*Y*							
$P_4(M,U)$	0.53	0.00							
$P_4(U,M)$	0.00	0.53							
NTL	*6*	*5*	*4*	*3*	*2*	*1*			
$P_5(M,U)$	1.00	1.00	0.75	0.41	0.00	0.00			
$P_5(U,M)$	0.00	0.00	0.00	0.00	0.41	0.67			
SL	*55*	*45*	*35*	*25*	*15*				
$P_6(M,U)$	0.00	0.00	0.00	0.89	1.00				
$P_6(U,M)$	1.00	1.00	0.00	0.00	0.00				
PV	*40+*	*40*	*30*	*25*	*20*	*15*	*10*	*5*	
$P_7(M,U)$	1.00	1.00	1.00	0.72	0.50	0.33	0.17	0.00	
$P_7(U,M)$	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	
TV	*500+*	*500*	*400*	*300*	*200*	*100*	*50*		
$P_8(M,U)$	1.00	1.00	0.67	0.50	0.33	0.17	0.00		
$P_8(U,M)$	0.00	0.00	0.00	0.00	0.00	0.00	0.67		
AG	*12*	*5.5*	*4*	*<4*					
$P_9(M,U)$	1.00	0.76	0.55	0.00					
$P_9(U,M)$	0.00	0.00	0.45	0.80					
DNC	*1000+*	*750*	*500*	*250*	*200*				
$P_{10}(M,U)$	1.00	0.50	0.00	0.00	0.00				
$P_{10}(U,M)$	0.00	0.00	0.35	0.75	1.00				

Step 4: Determine complete ranking scores of each alternative

Weighted multi-criteria preference index $\pi(M,U)$ for Mark over Unmark and $\pi(U,M)$ for Unmark over Mark are defined considering all the criteria:

$$\begin{cases} \pi(M,U) = \sum_{i=1}^{10} w_i P_i(M,U) \\ \pi(U,M) = \sum_{i=1}^{10} w_i P_i(U,M) \end{cases} \tag{8}$$

This index also takes values between 0 and 1, and represents the global intensity of preference between the Mark and Unmark crosswalk types. In order to rank the alternatives, positive, negative preference flows and complete ranking are defined in Equation (9).

$$\begin{cases} Positive\ outranking\ flow: \varphi^{+}(M) = \pi(M,U);\ \varphi^{+}(U) = \pi(U,M) \\ Negative\ outranking\ flow: \varphi^{-}(M) = \pi(U,M);\ \varphi^{-}(U) = \pi(M,U) \\ Complete\ ranking: \varphi(M) = \varphi^{+}(M) - \varphi^{-}(M);\ \varphi(U) = \varphi^{+}(U) - \varphi^{-}(U) \end{cases} \tag{9}$$

In Equation (9), if complete ranking $\varphi(M) > 0$, it is indicated that positive flow prevails while considering marking the crosswalks, and if $\varphi(\mathrm{U}) < 0$, it is indicated that negative flows prevail while considering unmarking the crosswalks. After all, the mark or unmark preference percentages are defined for final decisions in Equations (10) and (11). Final preference scores are converted into a 100% scale. If the difference between the two final scores is less than 20%, engineering judgment is highly recommended.

$$If\ \varphi(M) > 0 \begin{cases} \text{Mark Preference Percentage F(M)} = \frac{(1+\varphi(M))}{2} \times 100\% \\ \text{Unmark Preference Percentage F(U)} = 1 - \text{F(M)} \end{cases} \tag{10}$$

$$If\ \varphi(U) > 0 \begin{cases} \text{Mark Preference Percentage F(M)} = 1 - \text{F(U)} \\ \text{Unmark Preference Percentage F(U)} = \frac{(1+\varphi(U))}{2} \times 100\% \end{cases} \tag{11}$$

5.2.3 Interface of Mark/Unmark Choice Tool

The computational engine of the choice tool is implemented using Visual Basic for Application (VBA) programming in EXCEL. Attention to several notations should be observed before continuing further analysis. To begin with, resetting the input interface using the 'Reset' bottom is highly recommended in order to set all factors back to an initial status. Secondly, the multi-criteria should be input strictly following the instruction descriptions. A 'Run' button is used to turn on the calculation and output engine together; the weights are already input into the macro models. As discussed previously, if the difference between two preference scores is relatively small, the output will suggest Engineering Judgment (EJ) to assist the final decision.

The developed tool is analogous to travel demand models or pavement management systems that engineers use. Although a mathematical model with various equations and variables is included, the interface of the numerical guideline visualized in Figure 11 indicates that this tool is easy to manipulate.

In short, the Mark/Unmark Choice Tool will present the likelihood of using a certain type of crosswalk at unsignalized study sites. Besides, considering discussions with respect to speed limit and pedestrian volume, the weights for these variables will fluctuate according to specific values input into the model. To be specific, since speed limit is a critical variable for both safety and mobility, marked crosswalk wills not be considered when speed limit is equal to or higher than 40 mph. That is, when inputting a speed limit of 40 mph, the preference for the unmarked crosswalk will be nearly 90%. The analysis interface is quite user friendly and easy to operate. Agencies can easily adopt this product to analyze local intersections or their own intersections, the given adjustments can yield dramatic differences. In the following section, a case study involving field data in Nevada is presented to demonstrate how easy it is to operate the developed guideline.

Reset

Model Input Variable Description

Variables		Abb.	Evaluation	Input
C1	Policy Preference Tendency	PPT	1-Conservative, 2-Moderate, 3-Aggressive	2
C2	Geometry Layout of Intersection	GL	3-legs, 4-legs	4
C3	Pedestrian Accident Occurrence	PRC	Pedestrian related accidents, acc./yr	3
C4	Median Type	MT	0-No, 1-Yes	0
C5	Number of Travel Lanes	NTL	1-lane, 2-lanes, 3-lanes, 4-lanes, etc.	4
C6	Vehicle Speed Limit	SL	mph	35
C7	Pedestrian Volumes	PV	peds/hour	32
C8	Traffic Volumes	TV	vph	1066
C9	Available Gaps	AG	sec. Average available gaps.	5
C10	Distance to Nearby Crosswalk	DNC	ft. less than 500ft is considered as short distance.	1500

Run

Model Calculation Procedure

INPUT		WEIGHT	Pi(d)		Multi-Criteria Index	
			Mark	Unmark		
PPT	2	0.0559	0.0000	0.0000	π(M,U)	π(U,M)
GL	4	0.0304	0.0000	0.0000	0.526215	0.28153
PRC	3	0.1829	0.5333	0.0000	ϕ^+(M)	ϕ^-(M)
MT	0	0.0263	0.0000	0.5333	0.526215	0.28153
NTL	4	0.0337	0.7533	0.0000	ϕ^+(U)	ϕ^-(U)
SL	35	0.2072	0.0000	1.0000	0.28153	0.526215
PV	32	0.1892	1.0000	0.0000	ϕ(M)	ϕ(U)
TV	1066	0.0436	1.0000	0.0000	0.244685	-0.24468
AG	5	0.1339	0.5500	0.4500	F(M)	F(U)
DNC	1500	0.0969	1.0000	0.0000	0.6223	0.3777

Model Output Results

Output Results	Mark	Unmark
Preference Score	62%	38%
Decision	Yes	No

Figure 11 Interface of Mark/Unmark Choice Tool

5.3 Case Study

The developed guideline was applied in a case study involving 25 unsigalized intersections in Nevada. Two objectives of the case study section are, (i) test practicability and feasibility of the developed guideline; (ii) compare actual pedestrian crosswalk type with guidelines proposed as well as the FHWA guideline proposal.

An illustrative example is briefly displayed to demonstrate the advantages of applying the developed guideline first. Twenty-one unsignalized intersections in the City of Henderson and four in the City of Reno were selected as case study sites. Because agencies will have differences in preference and policies pertaining to the marking of crosswalks, different policy preference tendencies were assigned to the two study areas at first to check whether the proposed guideline reflected the actual preference. Currently, Reno has a relatively balanced number of marked versus unmarked crosswalks, whereas Henderson has a higher percentage of unmarked crosswalks.

5.3.1 Illustrative Example

An example is presented to analyze the N Virginia Street & 17th Street intersection in Reno, Nevada. This intersection is right next to the UNR campus where traffic volume is very high during peak hours. Also, because of the short distance (approximate 470 feet) from the N Sierra Street & US 395 signalized intersection, long queue spillback always occurred at this location. The pedestrian crosswalk was unmarked at this location until this study was conducted. A three-hour data collection period exhibited two phenomena at this intersection. Firstly, because of high traffic volume, the gaps for pedestrian to cross were relatively small. Further, since there was no marked crosswalk to guide pedestrians, they tend to walk across a certain distance away from the intersection. To sum up, this intersection was potentially dangerous with respect to both pedestrian safety and mobility and thus was a candidate for crosswalk markings. Hence, the developed choice tool was applied to analyze this specific location.

The geometry of this location consisted of a three-leg intersection with four undivided travel lanes. There were 2 pedestrian-related crashes in a five-year period from 2007 to 2011, and because this intersection has a relatively high interaction between vehicles and pedestrians, a marked crosswalk was preferable according to the conceptual guideline. The following discussion will focus on the likelihood of using either a marked or unmarked crosswalk to enhance pedestrian safety and mobility.

The input data of the choice tool are shown in Table 14, and the corresponding preference degrees filled in gray are illustrated in Table 15. Since Reno has a relatively neutral policy about pedestrian crosswalks, a moderate policy preference tendency factor was applied for this site.

Table 14 Input Data of Illustrative Example

Explanatory Factor	Value
Geometry Layout of Intersection (3-legs, 4-legs)	3
Median Type (0-No, 1-Yes)	0
Policy Preference Tendency (1-Conservative, 2-Moderate, 3-Aggressive)	2
Vehicle Speed Limit (mph)	35
Number of Travel Lanes (1-lane, 2-lanes, 3-lanes, 4-lanes, etc.)	4
Traffic Volumes (vph)	1098
Pedestrian Volumes	22
Pedestrian Accident Occurrence (Pedestrian related accidents, acc./yr)	0
Available Gaps (Average available gaps, sec)	3
Distance to Nearby Crosswalk (Less than 500 ft is considered as short distance ft)	466

Table 15 Preference Degrees of Illustrative Example

Input Variables		Preference Function Pi(d)						
Geometry Layout of Intersection	3	GL	4L	3L				
		$P_1(M,U)$	0.00	0.61				
		$P_1(U,M)$	0.00	0.00				
Median Type	0	MT	N	Y				
		$P_2(M,U)$	0.00	0.53				
		$P_1(U,M)$	0.53	0.00				
Policy Preference Tendency	2	PPT	1	2	3			
		$P_3(M,U)$	1.00	0.00	0.00			
		$P_3(U,M)$	0.00	0.00	1.00			
Available Gaps	3	AG	12	5.5	4	<4		
		$P_4(M,U)$	1.00	0.76	0.55	0.00		
		$P_4(U,M)$	0.00	0.00	0.45	0.80		
Vehicle Speed Limit	35	SL	55	45	35	25	15	
		$P_5(M,U)$	0.00	0.00	0.00	0.89	1.00	
		$P_5(U,M)$	1.00	1.00	0.00	0.00	0.00	
Distance to Nearby Crosswalk	466	DNC	1000	750	500	250	200	
		$P_6(M,U)$	1.00	0.50	0.00	0.00	0.00	
		$P_6(U,M)$	0.00	0.00	0.35	0.75	1.00	
Number of	4	NTL	6	5	4	3	2	1

Travel Lanes		$P_7(M,U)$	1.00	1.00	0.75	0.41	0.00	0.00			
		$P_7(U,M)$	0.00	0.00	0.00	0.00	0.41	0.67			
Traffic Volumes	1098	TV	500+	500	400	300	200	100	50		
		$P_8(M,U)$	1.00	1.00	0.67	0.50	0.33	0.17	0.00		
		$P_8(U,M)$	0.00	0.00	0.00	0.00	0.00	0.00	0.67		
Pedestrian Volumes	22	PV	40+	40	30	25	20	15	10	5	
		$P_9(M,U)$	1.00	1.00	1.00	0.72	0.50	0.33	0.00	0.00	
		$P_9(U,M)$	0.00	0.00	0.00	0.00	0.00	0.33	0.50	1.00	
Pedestrian Accident Occurrence	2	PRC	8	7	6	5	4	3	2	1	0
		$P_{10}(M,U)$	1.00	1.00	1.00	1.00	0.83	0.53	0.17	0.00	0.00
		$P_{10}(U,M)$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50

The preference index $\pi(M,U)$ and $\pi(U,M)$ are calculated based on Equation (8). The weight for each factor was calculated using the AHP approach. The most important factor in the new guideline is pedestrian-related crash records followed by the pedestrian volume factor. Further, the positive, negative preference flows and complete ranking scores are obtained afterwards based on Equation (9) and (10) as in Table 16.

Table 16 Summary of Preference Degrees and Ranking

Weight	*Summary of Pi(d)*		*Multi-Criteria Index*	
	Mark	Unmark		
0.0559	0.0000	0.0000	$\pi(M,U)$	$\pi(U,M)$
0.0304	0.6133	0.0000	0.418492	0.193859
0.1829	0.1667	0.0000	$\varphi^+(M)$	$\varphi^-(M)$
0.0263	0.0000	0.5333	0.418492	0.193859
0.0337	0.7533	0.0000	$\varphi^+(U)$	$\varphi^-(U)$
0.2072	0.9933	0.0000	0.193859	0.418492
0.1892	0.5000	0.0000	$\varphi(M)$	$\varphi(U)$
0.0436	1.0000	0.0000	0.224633	-0.22463
0.1339	0.0000	0.8000	F(M)	F(U)
0.0969	0.0000	0.7500	0.6123	0.3877

Table 17 Final Decision based on Choice Tool

Output Result	*Mark*	*Unmark*
Preference Score	61%	39%
Decision	Yes	No

The result indicated the preference score for marking this crosswalk was 61%, which is 22% higher than the unmark preference. Hence, the guideline recommends marking this pedestrian crosswalk considering all potential influence factors to guide pedestrian crossings. This result matches the decision made by the local agency. Shortly after this case study was conducted, a marked pedestrian crosswalk was installed at this location and so far there have been several positive comments regarding the construction.

5.3.2 Comparison Result

Twenty-five unsignalized intersections with 50% marked crosswalks and 50% unmarked crosswalks were analyzed. For intersections that already have marked crosswalks, an evaluation was conducted using the developed tool to check whether the marking is necessary or not. For intersections without marked crosswalks, a study was conducted to assess whether a marking was needed for the site. Table 18 exhibits essential intersection details in which the City of Henderson provided intersection information and pedestrian ADT at twenty-one locations, and field data collection was conducted at four locations in Reno.

Since the accuracy of results from the tool cannot be ascertained unless the models are calibrated to real world conditions, a model calibration was conducted. The policy preference tendency factor was input as 1-conservative, 2-moderate and 3-aggressive respectively. By comparing the existing conditions with numerical guideline recommendations, it was indicated that Henderson has a higher percentage of intersection crossings matching the aggressive judgment as shown in Figure 12. The matching results of Reno suggested that local agencies are prone to hold a moderate attitude when it comes to crosswalk marking. Hence, the corresponding preference tendency factors were applied to the study sites.

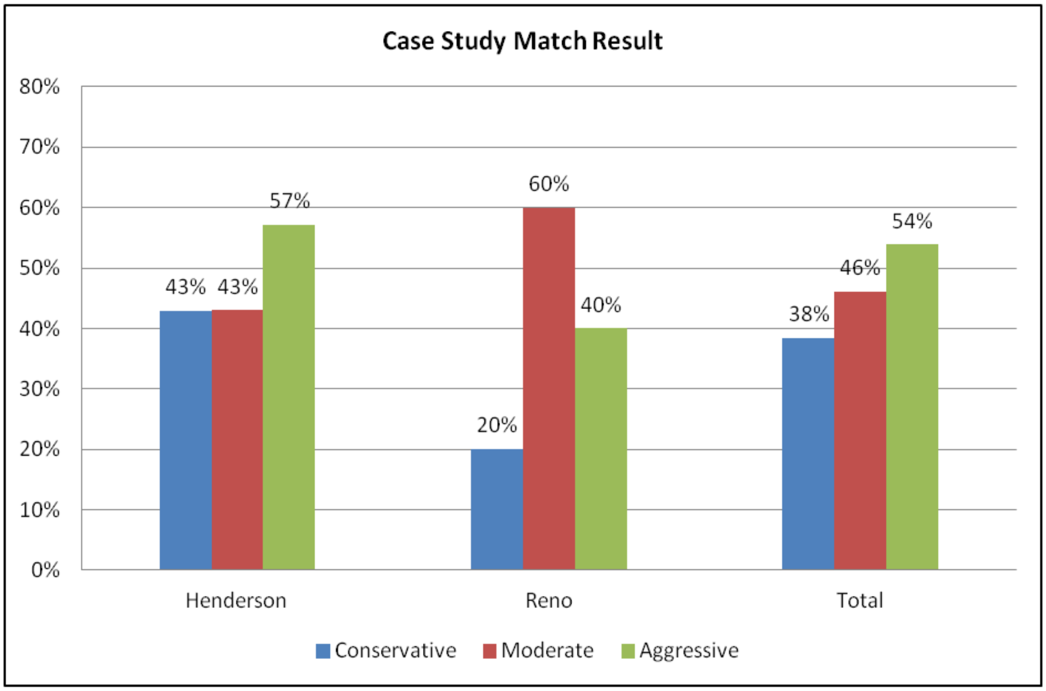

Figure 12 Case Study Match Results

Table 18 Case Study Field Data

City of Henderson	Input							Output	FHWA Guideline	Existing Crosswalk
	GL	PRC	MT	NTL	SL	PV	TV			
Horizon Ridge Pkwy & Annet St	4	0	1	6	45	5	250	Unmark	N	Unmark
Burkholder & Cloudcrest	3	1	0	5	35	60	500	Mark	P	Unmark
Anthem & Atchley	4	1	0	4	35	33	346	EJ	P	Mark
Amador Lane & Hoskins Court	3	0	0	2	45	21	129	Unmark	P	Unmark
Paseo Verd & Bella Vista Apts	4	3	1	6	55	39	1672	Unmark	N	Unmark
Green Valley & Paseo Verd	4	2	1	4	35	100	867	Mark	C	Mark
Alexandria & Anthem	3	3	1	4	55	24	1089	Unmark	N	Mark
Thunderbay & Sun City Anthem	4	0	1	4	35	7	633	Unmark	C	Unmark
Anthem & Somersworth	3	4	1	4	55	27	1211	Unmark	N	Mark
Jada & Solera Sky	4	0	0	2	45	43	183	Unmark	P	Unmark
Millcroft & Clayton	3	0	0	2	35	40	89	Unmark	C	Unmark
Sunset Way & Valle Verde	3	0	1	4	45	15	210	Unmark	P	Mark
High Mesa & Fountain Grove	3	0	0	2	35	9	68	Unmark	C	Unmark
Auto Mall & American Pacific	3	0	0	4	45	67	225	Unmark	N	Unmark
Democracy & Anthem Highlands	4	3	1	8	45	31	298	Unmark	P	Mark

Gibson & Mary Crest	4	0	1	5	45	51	321	Unmark	P	Unmark
Reunion Dr. & Cadence St.	3	2	0	4	35	54	259	Mark	P	Mark
American Pacific Dr & Cassia Wy	3	0	0	4	55	126	334	Unmark	N	Unmark
Van Wagenen St & Victory Rd	4	1	0	4	55	43	746	Unmark	N	Mark
Center & Fir	4	0	0	6	25	47	201	Mark	C	Unmark
Wigwam & Grand Legacy	3	2	0	5	35	234	1099	Mark	P	Mark
City of Reno				**Input**				**Output**	**FHWA**	**Existing**
	GL	**PRC**	**MT**	**NTL**	**SL**	**PV**	**TV**		**Guideline**	**Crosswalk**
W Moana Ln & Smith Dr	4	3	0	5	45	84	611	Unmark	N	Mark
Sutro St & Oliver Ave	3	0	0	6	35	61	940	Mark	P	Unmark
N.Virginia & 17th St	3	0	0	4	35	15	1098	EJ	P	Unmark
S Virginia St & La Rue Ave	4	2	0	5	35	24	329	Mark	P	Mark

Note: C—Candidate sites for marked crosswalks; P—Sites where probable increase in pedestrian crash risk may occur; N—Sites where marked crosswalks alone are insufficient.

Both of the results from the developed guideline and FHWA guideline were compared with actual field conditions. On one hand, approximate 72% of all guideline proposals matched actual field data. There are three reasons explaining the difference. Firstly, there was no consideration regarding pedestrian-related crash factors in either Reno or Henderson agencies when the crosswalks were installed. However, pedestrian crash record is an important factor in the proposed guideline. Even though both agencies took volume into account, it is more important to consider potential factors simultaneously and comprehensively as documented in the new guideline. Last but not least, the final preference scores are not divided into two categories, mark and unmark, but also into the engineering judgment category which is highly recommended when the difference between the two final scores is less than 20%. This category is not included in real world data.

About 60% of all recommendations based on the FHWA guideline confirm actual crosswalk types. At the same time, around 64% of the proposed guideline results met FHWA recommendations. Nevertheless, if merely considering combinations of vehicle

ADT, speed limit, number of travel lanes and median type which are the core of the FHWA guideline, the developed guideline will provide exactly the same results as the FHWA guideline. By complementing pedestrian volume, crash data and engineer preference factors, the developed guideline could accommodate more practical and insightful suggestions pertaining to crosswalk types.

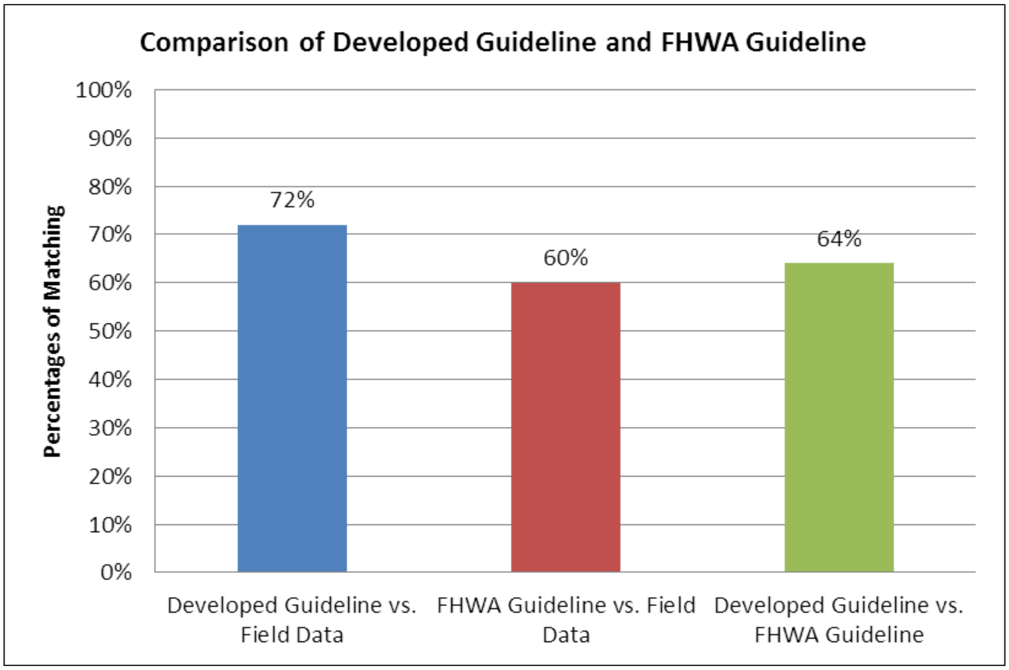

Figure 13 Comparison of the Developed Guideline and the FHWA Guideline

5.4 Summary and Conclusions

The guideline for marked and unmarked crosswalks at unsignalized intersections is a decision-making process resulting in the selection of a certain type of crosswalk. It is a cognitive process which involves recognizing the problem, identifying competing explanations for safety performance, putting forward a solution, and getting feedback on the solution. It is also a critical instruction toward people’s daily lives. Therefore, any potential confusion or misunderstanding must be avoided. Based on the limited guideline documented in the MUTCD and the Federal Guidance, this section developed a statewide guideline involving a descriptive conceptual guideline and a calculation tool to help select crosswalk types. The developed guideline corresponds with statewide survey results and the compared results justify the proposed method as effective in helping to decide crosswalk types.

6 CONCLUSIONS

The Nevada Strategic Highway Safety Plan (SHSP) has identified pedestrian issue as one of the five Critical Emphasis Areas (CEAs). Although the number of fatalities and injuries are improving both nationally and statewide, the vulnerability of this population continues to be a top priority. A large percent of pedestrian fatalities occurred in marked crosswalks, and the greatest proportion of pedestrian serious injuries and fatalities occurred at intersections. This study focuses on major crosswalk issues at unsignalized intersections to determine when a marked or unmarked crosswalk should be used. The literature review provides a comprehensive review of studies related to controversial discussions with respect to crosswalk markings. The safety analysis assesses the performance of both crosswalk types. And finally a statewide guideline was developed based on the fundamental guideline in the MUTCD. The following conclusions can be drawn based on this study.

- Crosswalk marking is a useful traffic control device, but it is very important for engineers and the general public to realize the positive as well as the negative consequences of marking crosswalks. Marked crosswalks appears to increase pedestrian mobility, but with perhaps a deceived sense of security.
- Marked crosswalks in Nevada involve higher pedestrian-related crash rates than unmarked crosswalks. This result is consistent with the majority of studies conducted previously in other States, like California, Florida, and Texas.
- There is still no clear-cut evidence to conclude whether marked or unmarked crosswalks are adequate for a site even though poor safety performance was found in Nevada sites because of two reasons. Firstly, pedestrian accident occurrence is not the only consideration in determining the need for a marked crosswalk. Merely marking a crosswalk could easily increase pedestrian accidents. Moreover,

the geometric layout of the intersections should also be a consideration to the extent that more complex intersection geometries are not conductive to safe pedestrian crossing with or without marked crosswalks. Therefore, an engineer study must be conducted before deciding on the installation of marked crosswalks.

- A general guideline layout incorporating key elements like volume and speed has been accepted by the majority of practicing traffic engineers. But there is no uniformity among those guidelines. On one hand, the descriptive statement in the MUTCD is not sufficient to make a clear decision whether marked or unmarked should be selected. On the other hand, the widely applied FHWA guideline does not take pedestrian demand and safety factor into consideration.
- The guideline for marked and unmarked crosswalks is a decision-making process. This decision-making process is a systematic process involving intricate decision rules especially when both mobility and safety factors are cogitated altogether. These factors have different categories and criteria thus the process can be considered a typical multi-criteria analysis problem.
- This study develops a statewide guideline for marked and unmarked crosswalks. Generally, marked crosswalks should be installed at locations where there is substantial conflict between vehicular and pedestrian movements, or there is a need to provide a path to direct pedestrians. Given specific sites, the developed Mark/Unmark Choice Tool shall be applied for final decision.
- As pointed out by the developed guideline, locations where the speed limit exceeds 40 mph should not consider for a marked crosswalk since it is not safe to guide pedestrians to cross. Also, when the distance between the study site and its nearby crosswalk is within a relatively short threshold, a marked crosswalk is not preferred either.

- At locations where a marked crosswalk is not recommended by the guideline, other countermeasures should be considered to maintain pedestrian safety and mobility.

Appendix I Test Values for Statistical Significance

The test values for statistical significance are shown in the following table (*37*).

N	Lower Limit	Upper Limit	N	Lower Limit	Upper Limit
1	0.02532	5.57164	50	0.74222	1.31838
2	0.1211	3.61234	51	0.74457	1.31482
3	0.20622	2.92242	52	0.74685	1.31137
4	0.27247	2.5604	53	0.74907	1.30802
5	0.3247	2.33367	54	0.75123	1.30478
6	0.36698	2.17658	55	0.75334	1.30164
7	0.40205	2.06038	56	0.75539	1.29858
8	0.43173	1.9704	57	0.75739	1.29562
9	0.45726	1.89831	58	0.75934	1.29273
10	0.47954	1.83904	59	0.76125	1.28993
11	0.4992	1.78928	60	0.76311	1.2872
12	0.51671	1.7468	61	0.76492	1.28454
13	0.53246	1.71003	62	0.76669	1.28195
14	0.54671	1.67783	63	0.76843	1.27943
15	0.55969	1.64935	64	0.77012	1.27698
16	0.57159	1.62394	65	0.77178	1.27458
17	0.58254	1.6011	66	0.7734	1.27225
18	0.59266	1.58043	67	0.77499	1.26996
19	0.60207	1.56162	68	0.77654	1.26774
20	0.61083	1.54442	69	0.77806	1.26556
21	0.61902	1.52861	70	0.77955	1.26344
22	0.62669	1.51401	71	0.78101	1.26136
23	0.63391	1.50049	72	0.78244	1.25933
24	0.64072	1.48792	73	0.78384	1.25735
25	0.64715	1.4762	74	0.78522	1.25541
26	0.65323	1.46523	75	0.78656	1.25351
27	0.65901	1.45495	76	0.78789	1.25165
28	0.66449	1.44528	77	0.78918	1.24983
29	0.66972	1.43617	78	0.79046	1.24805
30	0.6747	1.42756	79	0.79171	1.2463
31	0.67945	1.41942	80	0.79294	1.24459
32	0.684	1.4117	81	0.79414	1.24291
33	0.68835	1.40437	82	0.79533	1.24126
34	0.69253	1.3974	83	0.79649	1.23965
35	0.69654	1.39076	84	0.79764	1.23807
36	0.70039	1.38442	85	0.79876	1.23652
37	0.70409	1.37837	86	0.79987	1.23499
38	0.70766	1.37258	87	0.80096	1.2335
39	0.7111	1.36703	88	0.80203	1.23203
40	0.71441	1.36172	89	0.80308	1.23059
41	0.71762	1.35661	90	0.80412	1.22917
42	0.72071	1.35171	91	0.80514	1.22778
43	0.7237	1.34699	92	0.80614	1.22641
44	0.7266	1.34245	93	0.80713	1.22507
45	0.72941	1.33808	94	0.8081	1.22375
46	0.73213	1.33386	95	0.80906	1.22245
47	0.73476	1.32979	96	0.81	1.22117
48	0.73732	1.32585	97	0.81093	1.21992
49	0.73981	1.32205	98	0.81185	1.21868
			99	0.81275	1.21746

Appendix II Survey Questionnaire and Participants Information

Survey Questionnaire for Crosswalk Marking Policies in Nevada

(1) Do you currently have any guidelines or warrants regarding crosswalk marking?

- If yes, are the current guidelines sufficient? …………………………………………..
- Are there any issues with the application of those warrants? Any comments?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

- If yes, can you please attach the electronic file and/ or send a link with it?

(2) Which of the following in your estimation should be considered in setting up guidelines for crosswalk marking? (You can select more than one.)

A. Vehicle Volumes.

B. Pedestrian Volumes.

C. Vehicle Speed.

D. Sight Distance.

E. Number of Travel Lanes.

F. Median Type.

G. Pedestrian Accident Occurrence.

H. Geometric Layout of the Intersections.

I. Others. Please list other factors you think should be considered.

…………………………………………………………………………………………

Participants' Information

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Appendix III Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions. It was developed by Thomas L. Saaty in the 1970s based on mathematics and psychology and has been extensively studied and refined since then. This study uses the AHP approach to obtain the weights for input variables. The detailed procedure of the AHP method is outlined below.

Step 1: Study the problem and structure the problem into hierarchy

After analyzing the internal character and goals of the problem, structure the hierarchy into three levels from the top to the bottom including the objective from decision-makers' viewpoint, criteria used to evaluate the alternatives, and a list of alternatives.

Step 2: Compare and obtain the judgment matrix

A pair-wise comparison matrix for criteria is established by proficient based on qualitative scale measurement shown below. The proficient will rate the comparison as equal, marginally strong, strong, very strong, and extremely strong using numerical values as 1,3,5,7 and 9.

Table 19 Pair-Wise Comparison Scale Measurement for AHP

Intensity of Importance	*Definition*	*Explanation*
1	Equally important	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over another.
5	Much more important	Experience and judgment strongly favor one over another.
7	Very much more important	Experience and judgment very strongly favor one over another.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

Step 3: Obtain ranking priorities and weights

Priority vectors are composed of overall row averages of matrices after normalizing the column elements through dividing each element by the sum of the column indicated in Equation (12). To check the consistence index, the Eigenvalues could be gained by Equation (12) first.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix} \rightarrow \begin{bmatrix} b_{11} & \cdots & b_{1m} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mm} \end{bmatrix} \rightarrow \begin{bmatrix} x_1 \\ \vdots \\ x_m \end{bmatrix} = X \tag{12}$$

Where,

m—number of criteria;

A—comparison matrix of size $m \times m$, for m criteria, also called the priority matrix;

$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}$;

$x_i = \frac{\sum_{j=1}^{m} b_{ij}}{m}$;

X—priority vector of size $m \times 1$.

Additionally, based on $AX = \mu X$ the Eigenvalue μ can be found, $\mu > m$ and $\mu \in R$. Further, the Consistence Index is calculated as $CI = (\mu - m)/(m - 1)$, and Consistency Ratio is calculated as $CR = CI/RI(m)$, where $RI(m)$ is the index of consistency in row 2 and column m as shown in the following table. The consistency ratio (CR) is used to test the consistence of evaluation of AHP and should be less than 0.1.

Table 20 Index of Consistency for Random Adjustments

Size of matrix	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Index of consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Step 4: Rank priorities and obtain weights for each variable

Repeat Steps 2 and 3 to find the priority vector for each variable and test if the consistency ratios are less than 0.1. For this study, the weights are obtained as shown below.

Step1:A	EJ	GL	PRC	MT	NTL	SL	PV	TV	AG	DNC
EJ	1.00	1.00	0.17	5.00	5.00	0.11	0.25	1.00	0.33	0.17
GL	1.00	1.00	0.17	1.00	1.00	0.17	0.14	1.00	0.20	0.33
PRC	6.00	6.00	1.00	5.00	3.00	0.50	3.00	3.00	1.00	3.00
MT	0.20	1.00	0.20	1.00	1.00	0.11	0.20	0.50	0.33	0.17
NTL	0.20	1.00	0.33	1.00	1.00	0.17	0.33	1.00	0.25	0.25
SL	9.00	6.00	2.00	9.00	6.00	1.00	0.50	3.00	1.00	4.00
PV	4.00	7.00	0.33	5.00	3.00	2.00	1.00	3.00	3.00	3.00
TV	1.00	1.00	0.33	2.00	1.00	0.33	0.33	1.00	0.25	0.50
AG	3.00	5.00	1.00	3.00	4.00	1.00	0.33	4.00	1.00	2.00
DNC	6.00	3.00	0.33	6.00	4.00	0.25	0.33	2.00	0.50	1.00

Step2:B	EJ	GL	PRC	MT	NTL	SL	PV	TV	AG	DNC
EJ	0.03	0.03	0.03	0.13	0.17	0.02	0.04	0.05	0.04	0.01
GL	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.05	0.03	0.02
PRC	0.19	0.19	0.17	0.13	0.10	0.09	0.47	0.15	0.13	0.21
MT	0.01	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.04	0.01
NTL	0.01	0.03	0.06	0.03	0.03	0.03	0.05	0.05	0.03	0.02
SL	0.29	0.19	0.34	0.24	0.21	0.18	0.08	0.15	0.13	0.28
PV	0.13	0.22	0.06	0.13	0.10	0.35	0.16	0.15	0.38	0.21
TV	0.03	0.03	0.06	0.05	0.03	0.06	0.05	0.05	0.03	0.03
AG	0.10	0.16	0.17	0.08	0.14	0.18	0.05	0.21	0.13	0.14
DNC	0.19	0.09	0.06	0.16	0.14	0.04	0.05	0.10	0.06	0.07

Step3:X	Weight	Products	Ratio
x1	0.0559	0.5913	10.5705
x2	0.0304	0.3410	11.2195
x3	0.1829	2.1598	11.8096
x4	0.0263	0.2816	10.7085
x5	0.0337	0.3607	10.7182
x6	0.2072	2.4443	11.7946
x7	0.1892	2.1568	11.4018
x8	0.0436	0.4912	11.2714
x9	0.1339	1.4885	11.1140
x10	0.0969	1.1460	11.8246
SUM	1.00		

Step4:CR		
CI	0.1381	
CR	0.0980	<0.1

Figure 14 Weight of Each Variable based on AHP Approach

Appendix IV Multi-Criteria Methodology

Multi-criteria Decision Analysis

Multi-criteria decision analysis is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments (*38*). A multi-criteria decision problem can be described as a decision making problem with *m* criteria and *n* alternatives, and let $C_1, C_2 \cdots C_m$ and $A_1, A_2 \cdots A_n$ denote the criteria and alternatives, respectively. A standard feature of a multi-criteria decision making methodology is the decision matrix as shown in Equation (13). In the matrix, each row belongs to a criterion and each column describes the performance of an alternative. The score x_{ij} describes the performance of alternative A_j against criterion C_i. The global ranking value is then calculated as the product of the weight and scores. Usually, a higher value means a better performance of the alternative, so the alternative with the highest global ranking value is the best of the alternatives.

$$D = X_{ij} = \begin{array}{cc} & \\ & \\ w_1 & C_1 \\ w_2 & C_2 \\ \vdots & \vdots \\ \vdots & \vdots \\ w_m & C_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \\ A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{13}$$

In the decision matrix, weights $\{w_1, w_2, \cdots w_m\}$ are assigned to the criteria. Weight w_i reflects the relative importance of criteria C_i to the decision, and is assumed to be positive. The weight can be obtained separately using the Analytic Hierarchy Process (AHP) (*39*) method. The overall performance of each alternative is obtained by Equation (14).

$$F(A_j) = \sum_{i=1}^{m} w_i \, r_{ij} \tag{14}$$

Where, r_{ij} is defined as the normalized performance rating of alternative A_j against criterion C_i.

A wide range of multi-criteria decision analysis methods, such as the AHP approach (*39*), Simple Additive Weighting Method (*40*), TOPSIS Method (*41*), Outranking Methods can be applied to achieve a final ranking or scoring for the decision alternatives (*42*). Applications of decision support systems and multi-criterion decision making in particular to transportation are described in an interim report for NCHRP Project 20-29 (*43*). NCHRP Project 20-31 expanded the framework and developed a generic software package to facilitate the multimodal, multi-criterion transportation investment analysis for both freight and passenger transportation (*42*, *44*). Considering maneuverability and practical applicability, a developed guideline following the PROMETHEE method, a member of outranking methods, is proposed seeing mark and unmark as two alternatives in this study.

PROMETHEE Methodology

PROMETHEE methodology is a well-known member in outranking methods which solves complex choice problems with multiple criteria and multiple participants (*45*). The outranking methods are all well-known for their indication of the degree of dominance of one alternative over another. They enable the utilization of incomplete value information, for example, judgments on ordinal measurement scale (*46*). Also, they provide the partial preference ranking of the alternatives, not a cardinal measure of the preference relations. This methodology has been widely used, for example, for choosing the solid waste management system (*47*), for locating the waste treatment facility (*48*), for nuclear waste management (*49*) and other Environmental Impact Analysis (EIA) projects. However, the outranking concept does not possess a wide application in the transportation field. This study attempts to explore an approach assisting decision making tool with the advantages of this method.

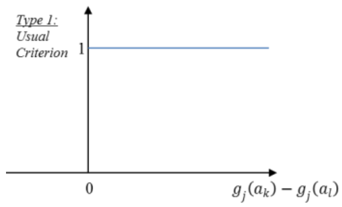
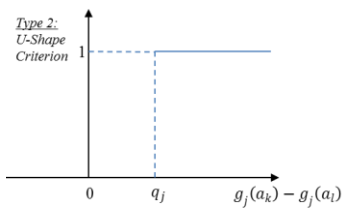
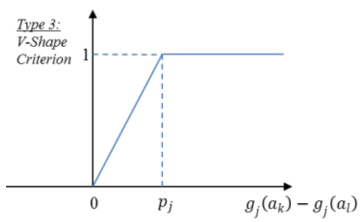
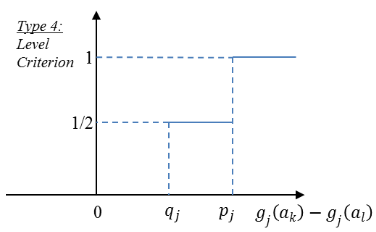
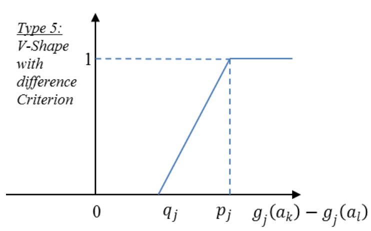
The PROMETHEE methodology is not allocating an intrinsic absolute utility to each alternative, neither globally, or on each criterion (*50*). The preference structure is based on pair wise comparisons similar to the AHP method. The deviance between the evaluations of alternatives on a particular criterion is considered. For small deviations, the decision-maker will allocate a small preference to the best alternative and even possibly no preference if it is considered that this deviation is negligible (*51*). That is, the larger the deviation, the larger the preference score. In the PROMETHEE method, the outranking degree $\prod(a_{k,}a_l)$ describes the credibility of the outranking relation that alternative a_k is better than alternative a_l. For each pair of alternatives $(a_{k,}a_l)$, the outranking degree is calculated using Equation (15).

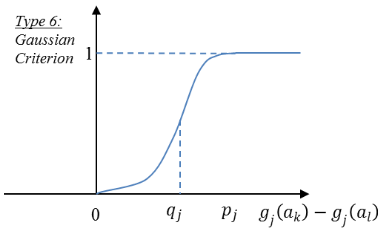
$$\prod\left(a_{k,}a_l\right) = \sum_{j=1}^{n} w_j F_j\left(a_{k,}a_l\right) \quad (15)$$

Where, $F_j(a_{k,}a_l)$ is the preference function; and w_j is the relative importance of the different criteria which scaled to add up to 1 in the formula.

In contrast to using the normalized subjective rating scores as Equation (2), PROMETHEE methodology uses a pre-defined preference function to pair wise compare the global performance of alternatives under different criteria. The preference function is the core of this method. The value $F_j(a_{k,}a_l)$ for a pair of alternatives a_k and a_l regarding criteria C_j is calculated using either one of the functions demonstrated in Table 1. In general, six different forms of the threshold function can be applied according to specific cases. The first two functions indicate that the preference is absolute yes or no, but the other four define an indifference range $[0, q]$ as well as a preference range $[p, \infty]$. Specifically, the parameter q defined as the indifference threshold is the largest deviation which is considered as negligible by the decision maker, while the parameter p defined as the preference threshold is the smallest deviation which is considered as sufficient to generate a full preference. If the deviance between alternatives falls into the range $[q, p]$, the preference function is defined as a linear or nonlinear function correspondingly.

Table 21 Preference Functions in PROMETHEE Methodology (41)

Preference Function	Definition	Paramet-ers
	$F_j(a_k, a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \le 0 \\ 1, & if\ g_j(a_k) - g_j(a_l) > 0 \end{cases}$	-
	$F_j(a_k, a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \le q_j \\ 1, & if\ g_j(a_k) - g_j(a_l) > q_j \end{cases}$	q
	$F_j(a_k, a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \le 0 \\ \dfrac{g_j(a_k) - g_j(a_l)}{p_j}, & if\ 0 \le g_j(a_k) - g_j(a_l) \le p_j \\ 1, & if\ 0 \le g_j(a_k) - g_j(a_l) > p_j \end{cases}$	p
	$F_j(a_k, a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \le q_j \\ 1/2, & if\ q_j \le g_j(a_k) - g_j(a_l) \le p_j \\ 1, & if\ g_j(a_k) - g_j(a_l) > p_j \end{cases}$	q, p
	$F_j(a_k, a_l) = \begin{cases} 1, & if\ g_j(a_k) - g_j(a_l) \ge p_j \\ 0, & if\ g_j(a_k) - g_j(a_l) \le q_j \\ \dfrac{g_j(a_k) - g_j(a_l) - q_j}{p_j - q_j}, & otherwise \end{cases}$	q, p

	$F_j(a_k, a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \le 0 \\ 1 - e^{-\frac{(g_j(a_k) - g_j(a_l))^2}{2s^2}}, & if\ g_j(a_k) - g_j(a_l) > 0 \end{cases}$	s

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