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Final Report

HOW TO MORE SAFELY ACCOMMODATE PEDESTRIANS THROUGH AN INTERSECTION WITH FREE FLOW LEGS

MINNESOTA DEPARTMENT OF TRANSPORTATION

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16. Abstract (Limit: 200 words)

Slip lanes (free-flow legs) help the traffic flow by allowing right turning traffic to continue through the intersection without having to stop on red. Yet, pedestrians are often unaware that right turning traffic is not required to stop as per the traffic lights when using the slip lane. Likewise, drivers often do not realize that pedestrians may be crossing the slip lane assuming the right-of-way. As such, the unresolved right-of-way puts pedestrians at risk. A national online survey was conducted, and an in-depth literature review was completed to identify potential countermeasures to promote pedestrian safety at slip-lanes. Numerous countermeasures were identified with a particular focus on communicating the presence of pedestrians crossing slip lanes to the drivers by means of novel, innovative, and effective traffic control devices. Six intersections were selected to monitor and record pedestrian and vehicle behaviors in slip lanes in Rochester, Minnesota. Potential countermeasures were evaluated for their effectiveness to convey the pedestrian presence information to the drivers, yet not interfering with the vehicle free-flow at other times. An automatic pedestrian-activated active in-sign and in-pavement flashing LED system was identified as the best candidate for implementation. An intersection was also selected among the six candidates to have the selected countermeasure be implemented.

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HOW TO MORE SAFELY ACCOMMODATE PEDESTRIANS THROUGH AN INTERSECTION WITH FREE-FLOW LEGS

Final Report

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Executive Summary

Free-flow legs (slip lanes) help the traffic flow by allowing right-turning vehicle traffic to continue through the intersection without having to stop on red. Yet, pedestrians trying to get across these free-flow legs are often unaware that right-turning traffic is not required to stop even though the mainline traffic stops on red. Likewise, drivers often do not realize that pedestrians may be crossing the slip lane assuming the right-of-way. As such, the miscommunication between right-turning traffic on a free-flow leg and pedestrians crossing the free-flow leg puts pedestrians at risk. Pedestrian injuries and fatalities in free-flow legs seem to originate from an ambiguity of the right-of-way, and a misinterpretation of the intended system principles. Drivers do not expect to see pedestrians on free flow legs, and pedestrians exercise their right-of-way while assuming that drivers are aware of them and their presence. Nevertheless, free-flow legs are desirable from a throughput standpoint, because they allow right-turning traffic to continue and merge crossing traffic without significant traffic disruption, and as such, increase the level of service.

The Minnesota Department of Transportation (Mn/DOT) recognized the pedestrian safety concern in free-flow leg operations as a priority. Mn/DOT thereby initiated a research study and contracted the Operator Performance Laboratory (OPL) of the University of Iowa to lead a project to identify a set of countermeasures that can be used in free-flow legs to promote pedestrian safety, while maintaining an acceptable level of service for the vehicles using the free-flow legs. As a part of the study, a national online survey was conducted, and an in-depth literature review was completed. Numerous countermeasures were identified with a particular emphasis on communicating the presence of pedestrians crossing slip lanes to the drivers by means of novel, innovative, and effective traffic control devices.

The most economical solutions are passive speed-reducing measures, which may cause permanent changes in the roadway structure for most practical purposes. Solutions that do not require changes in the roadway structure include internally-illuminated overhead crosswalk signs, and sensor activated in-ground and in-sign LEDs. These systems do not force drivers to slow down, but rather warn them. Internally-illuminated overhead crosswalk signs are passive warning systems that increase pedestrian visibility and indicate the possibility of crossing pedestrians (since it is not active). The infrared sensor-activated flashing in-ground and in-sign LEDs is a newer technology that features an active warning system. This active warning system indicates an almost certain real-time existence of pedestrians in a conspicuous fashion. Flashing lights are also known to capture and reorient visual attention much successfully than steady lights.

Potential countermeasures were evaluated for their effectiveness to convey the pedestrian presence information to the drivers, but otherwise not to interfere with the vehicle free-flow. The safety benefits of each alternative were considered in terms of their safety performance in similar applications based on the survey results. Furthermore, their potential effects on vehicle traffic flow in free-flow leg applications were determined in terms of speed reduction and roadway structure change requirements. Nevertheless, most passive speed reduction measures would be counterproductive from a free-flow point of view, because they slow the traffic regardless, even in the absence of pedestrians. Thus, neither a substantial speed reduction nor a permanent structure change in roadway was desired. Thus, an automatic pedestrian-activated active in-sign

and in-pavement flashing LED system was identified as a viable alternative, because it actively warns drivers when a pedestrian is present, whereas it functions as an unobtrusive passive pedestrian crosswalk sign at other times. As such technologies become more robust across various climatic and weather conditions and more reliable with trouble-free operation, we expect to see more of such technologies be implemented and safety benefits be observed.

Furthermore, six intersections with free-flow legs in Rochester, Minnesota area were selected for remote traffic monitoring and recording. A four-channel remote monitoring system was developed and tested for robust operation under adverse weather conditions. Cameras were mounted on traffic control masts with the help and guidance of city traffic engineers from the city of Rochester, and recorded the traffic and pedestrian flow unobtrusively at different times of the day within a period of two weeks. The recordings were analyzed in the laboratory using an event-matching technique to determine the pedestrian and driver behaviors in free-flow legs, and then select one intersection for possible countermeasure deployment. The intersection of 14th Street and Broadway Street was selected as a key site for possible countermeasure deployment. This site had the highest pedestrian traffic volumes and pedestrian-vehicle conflicts during the monitoring period, which promises a fast yet effective evaluation of various countermeasures.

Assessment of the safety benefits of the feasible countermeasures can be determined only after the implementation of such countermeasures and an in-depth analysis of vehicle and pedestrian flow through free-flow legs. Different countermeasures can be implemented at separate yet similar sites and pedestrian and driver behaviors in the free-flow legs can be monitored *before* and *after* the implementation of the countermeasures to determine the changes in driver understanding of pedestrian presence and behavior. A control site similar to the test sites in terms of vehicle and pedestrian volumes also needs to be monitored to determine the changes in the traffic parameters with time. We believe that Mn/DOT will benefit using the selected key intersection in assessing the safety performance of any of the countermeasures, and starting with the suggested crosswalk system as a countermeasure may provide a great margin of safety for pedestrians in free-flow legs.

Chapter 1
Introduction

The use of free-flow legs, or right turn slip lanes at intersections, has become an increasingly common practice in numerous states throughout the nation. They are sometimes used at unsignalized intersections to provide traffic with smoother turning maneuvers. A slip lane is a right hand turn lane in an intersection that is separated from the non-turning lanes by an island, sometimes referred to as a pork-chop or a refuge island. Traffic through the free-flow legs is not required to stop, except when there is crossing traffic or pedestrians. Nevertheless, it is difficult to safely get pedestrians across such intersections.

Free-flow legs are efficient from an intersection vehicle throughput point of view, in that they allow the right-turning traffic to continue without necessarily stopping. However, drivers on free flow legs do not expect crossing pedestrians and may therefore not be prepared to stop and avoid pedestrians. As such, prevailing speeds in free flow legs are rather high, and pedestrian accidents are quite often fatal, and the associated costs, liability, and loss of lives are usually substantial. This project aims to address the need in identifying an effective countermeasure that will improve pedestrian safety in free-flow legs while maintaining the level of service for the motorized traffic using the free-flow legs.

The Minnesota Department of Transportation is looking for a way to improve safety at slip lanes for both pedestrians and drivers. The goal of this research study is to identify effective methodologies and countermeasures to reduce pedestrian accidents at intersections with free-flow legs, thereby to aid Minnesota Department of Transportation (Mn/DOT) in promoting pedestrian safety.

1.1. Statement of the Problem

Free-Flow legs, or right turn slip lanes, are a very effective and efficient intersection design from a traffic flow point of view. Slip lanes help the traffic flow by allowing right turning traffic to continue through the intersection without having to stop for a red light. This intersection design, however, may pose a threat to pedestrians. Often, drivers do not realize that pedestrians may be crossing this right hand lane of traffic. Pedestrians may also be unaware that right turning traffic is not required to stop as per the traffic lights when using the slip lane. These two factors contribute to the number of pedestrian/vehicle conflicts.

1.2. Objectives

The objective of this research is to provide the Minnesota Department of Transportation with a set of traffic engineering and design measures to improve pedestrian safety at intersections with free-flow legs by primarily modifying the driver behavior in a positive way.

This report includes an in-depth review of the technical literature, a national and international survey of pedestrian safety and pedestrian movements at free-flow legs, and video field observations and analysis of vehicle and pedestrian movements at six selected intersections where pedestrian/vehicle conflicts are common. The videos were analyzed using an event-matching technique. The primary measure of effectiveness (MOE) for the selected traffic engineering treatments was the number of pedestrian-vehicle conflicts. Among the alternative design measures, one alternative was identified as the most promising in actively grabbing driver attention while pedestrians are present in the crosswalk, yet at other times act as a passive warning.

The purpose of video surveillance of various intersections in Olmsted County was to further our understanding of driver and pedestrian behavior on free-flow legs, and as such, to identify a key intersection for a possible future study, through which, a selected countermeasure is implemented and its effectiveness is determined.

The upcoming chapters are organized as follows: Chapter 2 outlines the findings of the in-depth literature review, Chapter 3 summarizes the national and international survey and its findings, Chapter 4 describes the six candidate intersections, Chapter 5 describes the procedure, equipment, and analysis techniques used in intersection monitoring and selection, Chapter 6 details the countermeasure alternatives, as well as a human factors approach and engineering judgment in determining the best candidate countermeasure, and Chapter 7 summarizes the research findings and gives a brief discussion of the research topic and further directions.

Chapter 2
Review of Relevant Technical Literature

Research on slip lanes and other intersections was conducted through a variety of technical databases in the traffic engineering field. Government publications included those from the Federal Highway Administration along with national and international departments of transportations. Publications of various organizations, associations, and committees, working to improve pedestrian safety also provided useful information on the statistics and standards for intersection design. Further resources will be discussed in the following section.

Transport Canada published a study containing statistics regarding pedestrian fatalities and injuries from 1988 to 1997 [1]. This study was conducted over this ten year period, and illustrated the trends of pedestrian fatalities in various age groups. According to the study, pedestrian fatalities averaged 486, and pedestrian injuries averaged 15,358 per year. 94 percent of the pedestrian injuries and 70 percent of the fatalities occurred in urban areas. In terms of gender, males represented 61.5 percent of pedestrian fatalities, while females accounted for 38.5 percent of the pedestrian fatalities. The 65+ age group accounted for 25 percent and 38 percent of male and female fatalities, respectively. Figure 2.1 and Figure 2.2 show the average number of pedestrian injuries and fatalities over the ten-year period for both females and males, grouped according to age.

The National Center for Bicycling and Walking [2] is an organization that is concerned with improving the safety of roads for cyclists and pedestrians. The organization published a number of studies providing possible solutions to the problem of car and pedestrian crashes. Some of the solutions included improved pedestrian conspicuity, decreasing the distance, while increasing the time that pedestrians have to cross a roadway, slowing motor vehicles, and ease of movement from walkway to street levels and vice versa. Because the slip lane intersections of interest in Minnesota have already been installed, some of these solutions may not be relevant; however, these solutions should not be discounted for future intersection design and the setting of standards and guidelines. Another suggestion made by the National Center for Bicycling and Walking is to develop a “standard” for intersection set-up. Uniformity is an important design principle because it reduces the ambiguity and guesswork for the users of the intersection. When a motorist is faced with a new driving situation, they may not fully understand the rules that apply, therefore, developing a standard will reduce the risk by providing a rule-based environment. By standardizing the slip lanes and educating drivers and pedestrians, the users’ situation awareness can be improved, which in return minimize the risk of crashes and conflicts.

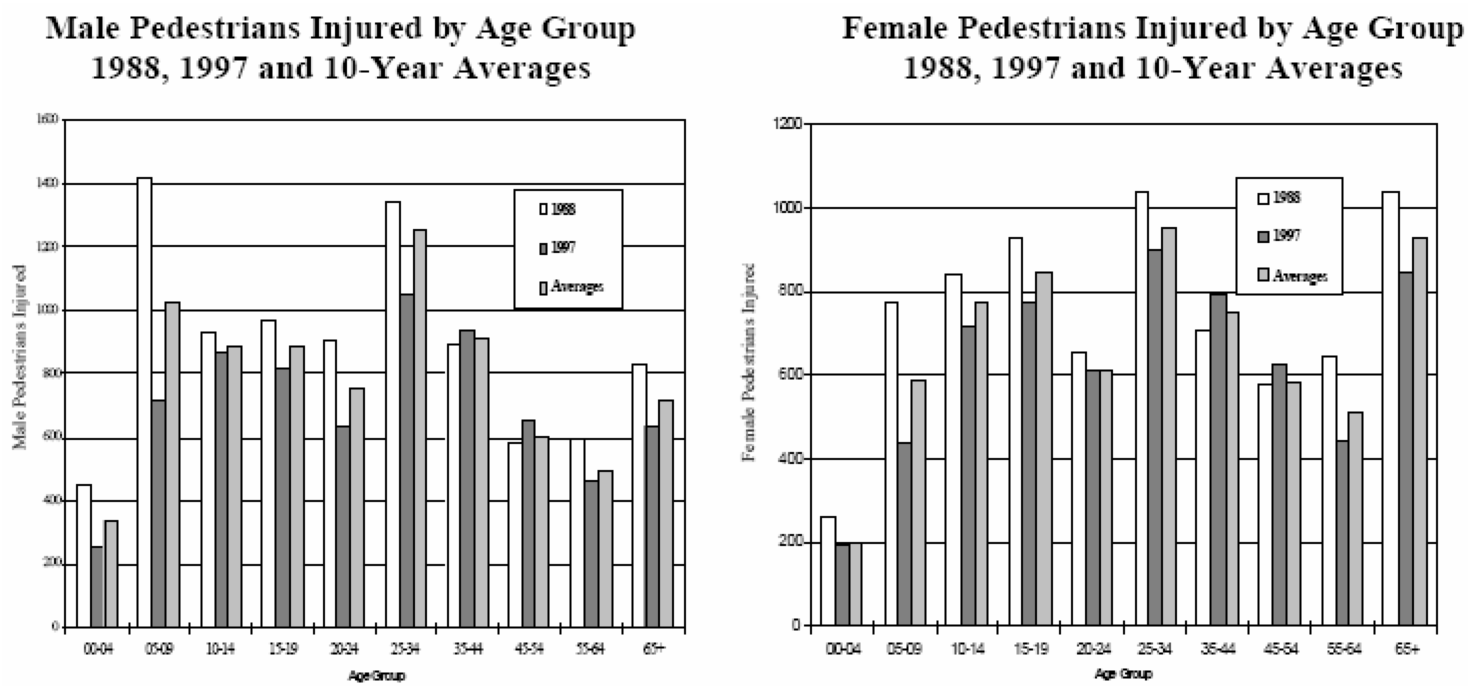
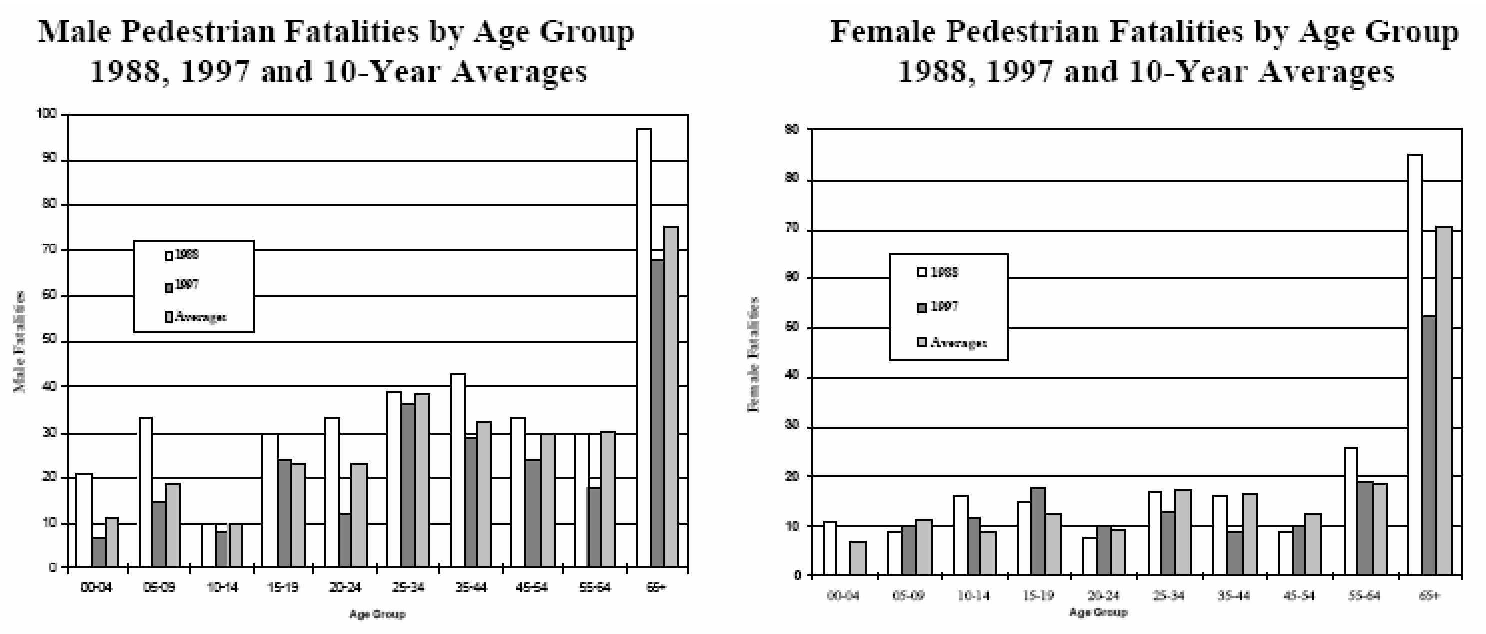


Figure 2.1. Average number of pedestrian injuries over the ten-year study conducted by Transport Canada.

Source: [1].



Source: [1].

Figure 2.2. Average number of pedestrian fatalities over the ten-year study conducted by Transport Canada

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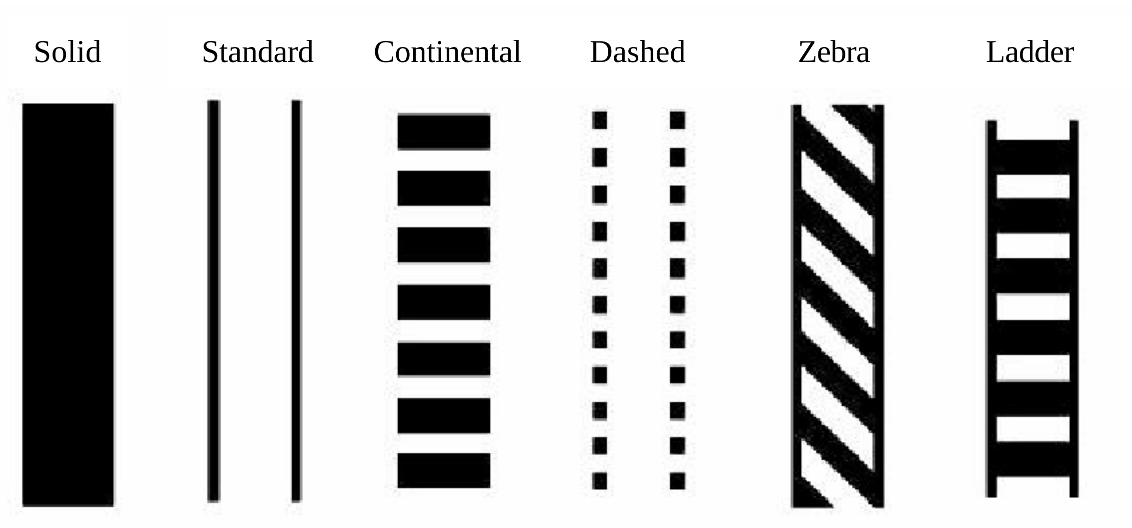
The Transportation Research Board publishes journals annually on a variety of issues concerning transportation and safety. One such relevant journal was the report entitled "Pedestrian and Bicycle Transportation Research for 2000" [3]. This journal provides information on the effects of different types of pedestrian signs at intersections throughout the USA and Canada. These signals and signs include illuminated overhead crosswalk signs, an overhead flashing beacon with a pedestrian symbol, and pedestrian safety cones. This journal also presents statistics on the before and after conditions for each type of signal or sign.

Federal Highway Administration provides substantial information on pedestrian safety. Through its web site, the FHWA provides insight into pedestrian safety improvements for intersections. The web site includes a section on slip lanes and considerations for their design [4]. It outlines the problems that occur when motorists fail to acknowledge pedestrians crossing the slip lane. This web site also provides recommendations for pedestrian push-button crossings, including an appropriate height for the button, signs indicating the exact street that can be crossed when activated, and the use of illuminated buttons such as those used in elevators to give feedback that the button was pressed. Another recommendation is to use a signal that looks like a pair of eyes looking both ways. This is used to encourage pedestrians to watch for turning cars while crossing the intersection.

Portland Pedestrian Design Guide, City of Portland's Office of Transportation provides valuable design considerations for pedestrian crossings [5]. This document provided recommendations regarding the placement of the crosswalk markings in order to help the motorists and pedestrians clearly identify the crosswalk location. The design guide also examines the effect of different types of pavement markings for crosswalks. Some of the different types are shown in Figure 2.3.



Source: [6].

Figure 2.3. Different pavement markings for crosswalks.

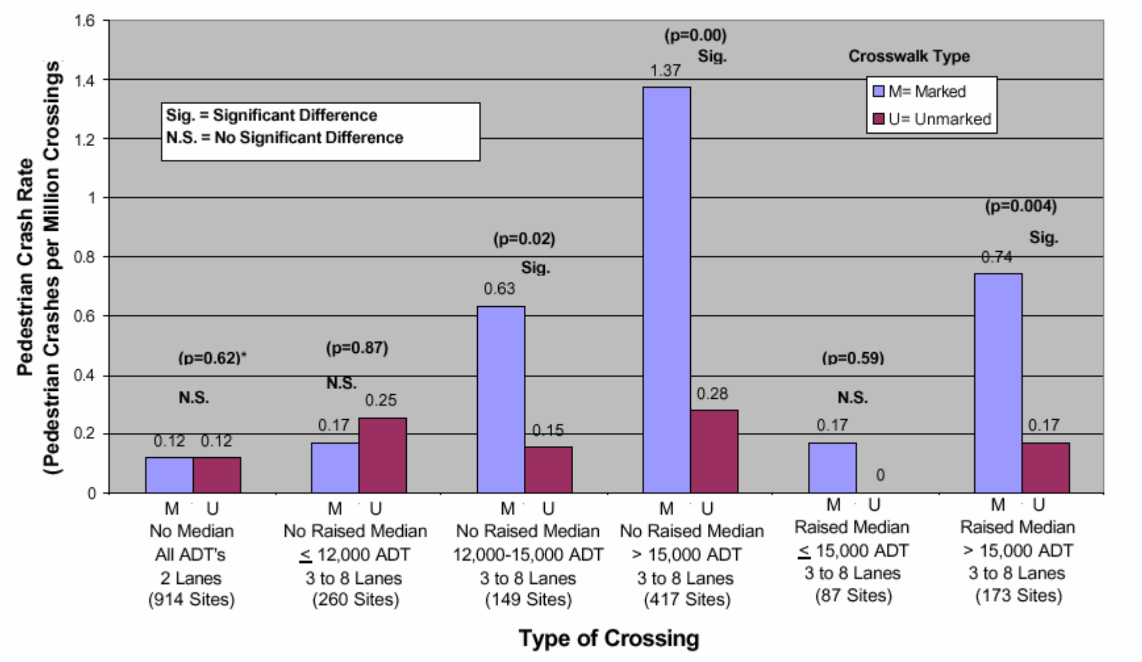
There have been many debates on whether marked but uncontrolled crosswalks in fact assist pedestrians and improve safety while crossing the street. According to a study conducted by Zegeer, Steward, Huang, and Lagerwey, pedestrians consider marked crosswalks a tool to aid them safely through an intersection [6]. Pedestrians see the crosswalk as a way for them to share the road with traffic. They may also think that the driver will be able to see the crosswalk markings as well as they do, and they assume that it will be safer to cross where drivers can see the white crosswalk lines. However, this may not always be true. Many times the driver cannot see the crosswalk, unless it is raised or marked with a sign. This situation may be particularly relevant to the intersections being studied in Minnesota, because several months a year, crosswalk markings may be hidden under snow or ice. To first study the effects of pavement markings, one must know the definition of a crosswalk. The 1992 Uniform Vehicle Code (Section 1-112) defines a crosswalk as:

(a) That part of a roadway 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 traversal roadway; and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline.

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

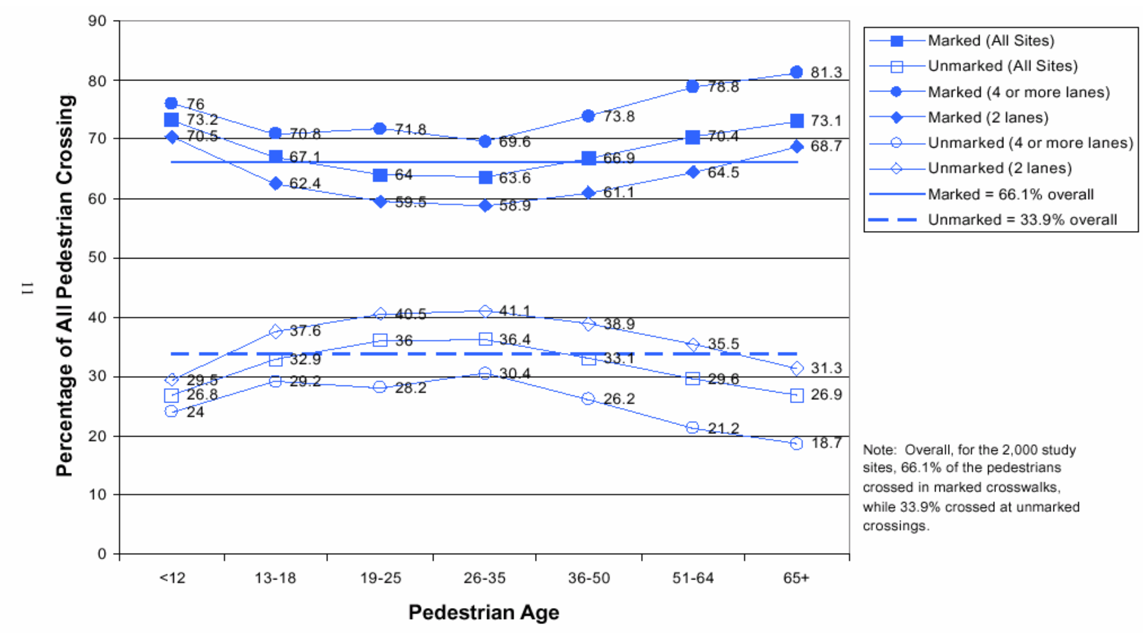
According Zeeger et al. [6], it was discovered that on two lane roads there was no significant difference in pedestrian crashes for marked vs. unmarked crosswalk sites. However, on multi-lane roads there was a higher fatality rate when pedestrians used the marked crosswalks compared to unmarked intersections. These results may be somewhat expected albeit unfortunate, since it is very difficult for people to cross multiple lanes of traffic successfully. The crosswalks may have increased the number of "at risk" pedestrians, because pedestrians sometimes mistakenly assume that the vehicle traffic will stop for them. This finding may also be in part due to the higher number of pedestrians willing to use the marked crossroads rather than unmarked ones. Unfortunately, simply installing a marked crosswalk without other more substantial crossing facilities often does not result in the majority of motorists yielding to pedestrians, contrary to the expectations of many pedestrians. Figure 2.4 shows pedestrian crash rates on various types of crosswalks.

Zegeer, Steward, Huang, and Lagerwey [6] also analyzed the percentage of pedestrian crossing at marked and unmarked crosswalks by age group and road type. Among over 1000 unmarked and 1000 marked crosswalks, 66.1% of pedestrians crossed at the marked while only 33.9% at unmarked crosswalks. More than 70% of pedestrians under the age 12 and above the age 64 years crossed at marked crosswalks. Similarly, about 65% of pedestrians in the 19- to 35-year-old range crossed at marked crossings. An even greater percentage of older adults (81.3 percent) and young children (76.0 percent) chose to cross in marked crosswalks on multi-lane roads compared to two-lane roads. Thus, installing a marked crosswalk at an already undesirable crossing location (i.e., wide, high-volume street) may increase the chance of pedestrian crashes, especially when no additional warning system is provided. Figure 2.5 illustrates the percentage of pedestrians using marked vs. unmarked crosswalks.



Source: [6].

Figure 2.4. Pedestrian crash type vs. type of crossing.



Source: [6].

Figure 2.5. Percentage of pedestrians crossing at marked and unmarked crosswalks.

The percentage of crashes in nighttime did not seem to differ between the crosswalk types, in that, 30% of all crashes were in nighttime in both the marked and unmarked crosswalks. However, during the day there were more crashes in the marked crosswalks during busy times, i.e. 6am-10am and 3pm-7pm. In contrast, during the midday and evening hours (10am-3pm and 7pm to midnight) there were fewer crashes in the marked crosswalks. This may be in part due to people walking in the marked crosswalks during busy travel time, i.e. driving and walking to work or school [6].

A study conducted by Nitzburg and Knoblauch [7], also focused on the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections. One aspect of the field data collection effort was to determine if pedestrians were more likely to cross a street from a marked crosswalk. A second aspect of the study was to determine if drivers drove slower or yielded more often to pedestrians crossing at a marked location. Another objective of the study was to determine if pedestrians use more, less, or the same amount of caution when crossing at a marked pedestrian crosswalk as opposed to an unmarked one.

It was found that drivers approach a pedestrian in a crosswalk somewhat slower, and that crosswalk usage increased after markings were installed. No evidence was found indicating that pedestrians were less vigilant in a marked crosswalk. No changes were found in driver yielding or pedestrian assertiveness. Overall, it appears that marking pedestrian crosswalks at relatively low-speed, low-volume, unsignalized intersections are a desirable practice, based on the sample of sites used in this study [7].

In addition, Nitzburg and Knoblauch [7] found that vehicles failing to yield on through movement lanes or slip lanes accounted for a large number of crashes (41.5% in the marked crosswalks and 31.7% in the unmarked crosswalks). These results indicate a need to better educate the drivers that pedestrians are and will be crossing. Drivers need to be warned that there is a possibility of people crossing, and that they must stop or yield.

In [7], it was also found that drivers were 30 to 40 percent more likely to slow and yield at the locations where the overhead crosswalk signs were installed. The traffic volumes for the study are listed in Table 2.1. The high visibility crosswalk sites (sites 1 & 3) included intersections with both marked crosswalk markings and overhead signs. At the first control site (site 2), there were no crosswalk markings or signs, whereas at the second control site (site 4) there were standard crosswalk markings.

Table 2.1. Traffic volumes at four different pedestrian crossing sites

Site No.	Site Type	Traffic Volumes (VPH)			
		Southbound		Northbound	
		Mean	Std Dev	Mean	Std Dev
1	Experimental: high-visibility crosswalk, refuge island	718.9	154.84	584.7	122.86
2	Control: no crosswalk markings—intersection	427.2	109.57	566.4	175.53
3	Experimental: high-visibility crosswalk, refuge island	626.7	150.69	548.0	70.74
4	Control: standard crosswalk marking—mid-block	663.6	147.08	542.4	104.74

Source: [7].

In terms of the way the pedestrians watched for traffic when crossing the street, no difference was found between unmarked and marked crosswalks. However, more pedestrians used crosswalks with pavement markings and overhead lighted signs. At the high-visibility crosswalks 92.9% and 91.1% used the crosswalks for the first half of the street for sites 1 & 3 respectively, while 98.0% used the standard crosswalk at site 4. These numbers were slightly less for the second half of the crossing. A summary of the data is presented in Table 2.2. The relatively high percentage of pedestrians using the crosswalk, especially in the first half of crossing suggests that pedestrians felt an extra margin of safety when using the crosswalks, even though they needed to walk a little more.

Table 2.2. Percent of pedestrians using the crosswalks in marked and unmarked locations

Site No.	Site Type	Percentage of Pedestrians Using Crosswalk	
		1st Half of Crossing	2nd Half of Crossing
1	Experimental: high-visibility crosswalk, refuge island	92.9%	77.6%
2	Control: no crosswalk markings—intersection	56.5%	39.1%
3	Experimental: high-visibility crosswalk, refuge island	91.1%	82.3%
4	Control: standard crosswalk marking—mid-block	98.0%	72.5%

Source: [7].

Nitzburg and Knoblauch [7] also examined occurrences of pedestrians forcing the right of way (assertively using the crosswalk and expect the vehicle to stop). The goal of the Right of Way study was to determine if the pedestrians with the more visible crosswalk would feel safer walking out into the street and having the cars stop for them. The results were controversial, as shown in Table 2.3. In site 2 (no crosswalk markings), it was seen that for the second half of the crossing the pedestrians did not attempt to force the right of way at all. For site 3 (high-visibility crosswalk), the percentage of pedestrians forcing the right of way at the second half were three times as high as that in the first half. However, the differences were not statistically significant, and as such, it was not clear if high-visibility crosswalks increased pedestrian confidence or aggressiveness.

Table 2.3. Pedestrian forced right of way

Site No.	Site Type	Pedestrian Forced Right of Way	
		1st Half of Crossing	2nd Half of Crossing
1	Experimental: high-visibility crosswalk, refuge island	8.6%	8.6%
2	Control: no crosswalk markings—intersection	8.7%	0.0%
3	Experimental: high-visibility crosswalk, refuge island	3.8%	11.4%
4	Control: standard crosswalk marking—mid-block	7.8%	15.7%

Source: [7].

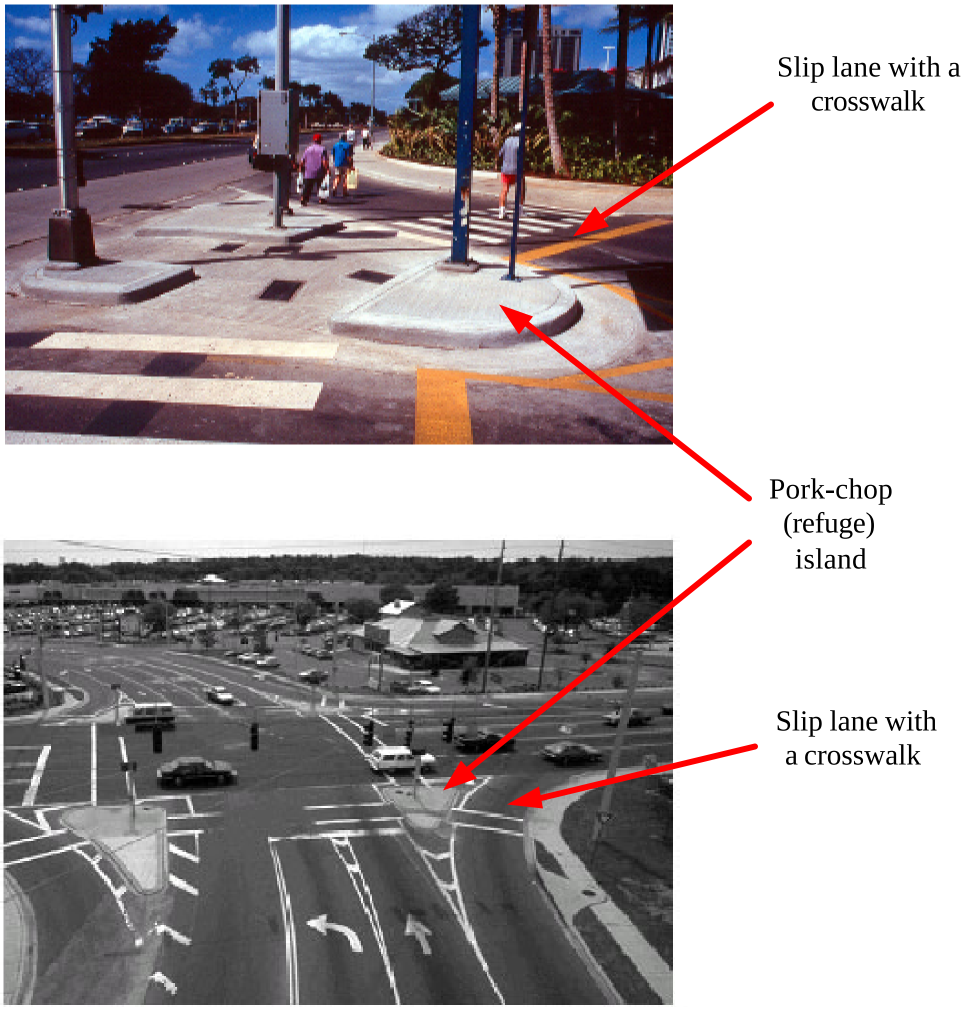
2.1. Slip Lane Intersections

Right turn slip lanes are free-flow extensions separate from the main flow, that allow the right turning traffic to move freely regardless of mainline traffic signaling. The slip lane is physically separated from the originating street by a small refuge island that is sometimes referred to as a pork-chop because of its shape. An example of a typical slip lane is given in Figure 2.6.

There are incentives that merit the use of slip lanes. First and foremost, slip lanes increase traffic throughput, by allowing the traffic to move freely and thereby reducing the traffic congesting at the intersection. Slip lanes are separate lanes for right turns so the only traffic present in this lane will be right-turning traffic. The promise of high traffic flow efficiency promotes the use of right turn slip especially at controlled high-volume surface intersections.

However, there is a downside of the slip lanes in the current state of implementation. Often, drivers do not realize that pedestrians may be crossing this right hand lane of traffic. Pedestrians may also be unaware that the traffic lights control only the main line, and the right turning traffic is not always required to when the through traffic stops.

Pedestrian safety at slip lane intersections can be improved by shortening the crossing distance and improving the visibility of pedestrians [8]. The pork-chop islands can help accommodate pedestrians when properly designed and sized. Their design should prevent high free-flow speeds. The pedestrian crossings should be placed where the motorist can easily see the pedestrian crossing adequately in advance. Necessary signals and signs that can remind motorists of their duty to yield to pedestrians when turning will also be helpful.

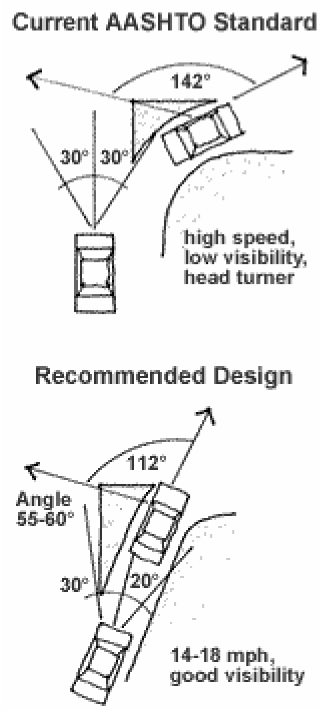


Source: Transportation Research Board and FHWA.

Figure 2.6. A slip lane in Hawaii and an overhead view of a right turn slip lane.

The current design of most right turn slip lanes complies with the standards of the AASHTO. This design is shown in Figure 2.7. However, this design has been challenged by a more efficient and pedestrian friendly design. The proposed design emphasizes the concept of high visibility slip lanes as shown in Figure 2.7. The former slip lane design prioritizes the high-speed throughput, at an expense of low pedestrian and cross-traffic visibility. The lane is a constant radius slip lane with a shallow exit angle that discourages stopping and typically require the driver turn their heads over 50 degrees over their shoulders to check for cross-street traffic (Florida DOT). The more modern design proposes a smaller radius turn, which requires slower approach speeds and enhances visibility. The new design also allows the drivers see the cross traffic without turning their heads too far left, thereby maintaining the car in front of them in the useful field of view, which reduces the risk of rear-end collisions [2]. A crosswalk should be placed six meters in front of the spot where the vehicles merge, this way the motorist can devote full attention to the cross-walk rather than the cross-traffic [5].

The current designs of many slip lanes merely use marked crosswalks as a precautionary measure. Some slip lane intersections do not even use marked crosswalks, but only the pork-chop serves as a refuge island for the pedestrians.



Source: [9].

Figure 2.7. Current and recommended slip lane designs.

Chapter 3
National and International Survey of Design Practices and Standards for Pedestrian Integration at Intersections with Free Flow Legs

3.1. Objective and Target Audience

A national and international survey was designed and deployed to determine the current practices in intersection design with a particular emphasis on pedestrian crossing at free flow legs in the US and worldwide. The goal of this survey was to identify design strategies that have been proven to be ineffective or even detrimental to pedestrian safety. Member of TRB, AASHTO, ITE, FHWA, and other agencies or associates were solicited about their expertise in the field of pedestrian integration at intersection design for their valuable input. Surveys were also sent to numerous state traffic engineers in the US and providence traffic engineers in Canada. This task was expected to yield a set of promising traffic engineering and design measures to improve pedestrian safety by positively affecting driving behavior at pedestrian crossings, especially those at free flow leg intersections.

3.2. Method

The survey was web-based and the hyperlink was e-mailed to the traffic engineers, which can be reached online at:

http://opl.ecn.uiowa.edu/MNDOT/sliplane survey/finalsurvey5.html

The results of the survey were collected using *php* scripting, which saved each respondent's response in a text file on the server side, inside an online folder with restricted access. The survey content is shown in Appendix A.

3.3. Results

The survey results are summarized in Appendix A, starting on page 45.

Chapter 4
Selection and Documentation of Six Intersections in the Field

4.1. Selection of Intersections

Six intersections within the Rochester, Minnesota area, in Olmsted county were selected as investigation sites. The intersections were selected based on the following criteria:

- Inclusion of a free flow leg in the intersection layout.
- Pedestrian protected crosswalks at the other segments of the intersection, and preferably accompanying sidewalks on either side.
- A high probability of interactions between vehicles and pedestrians based on the pedestrian flow and traffic flow.
- Recommendations from the Mn/DOT and Rochester Traffic Engineers.

4.1.1. Intersection 1

Intersection 1 is the intersection of CSAH 22 (Salem Rd SW) and CSAH 8 (Bamber Valley Rd SW) in Rochester, MN. Figure 4.1 shows an overall view, and Figure 4.2 shows a birds eye view of the intersection.

Figure 4.1. Intersection 1.

Source: [10]

Figure 4.2. Aerial view of Intersection 1.

4.1.2. Intersection 2

Intersection 2 is the intersection of TH 14 N. Frontage Rd NW and CSAH 22 (W Circle Dr NW) in Rochester, MN (Figure 4.3).

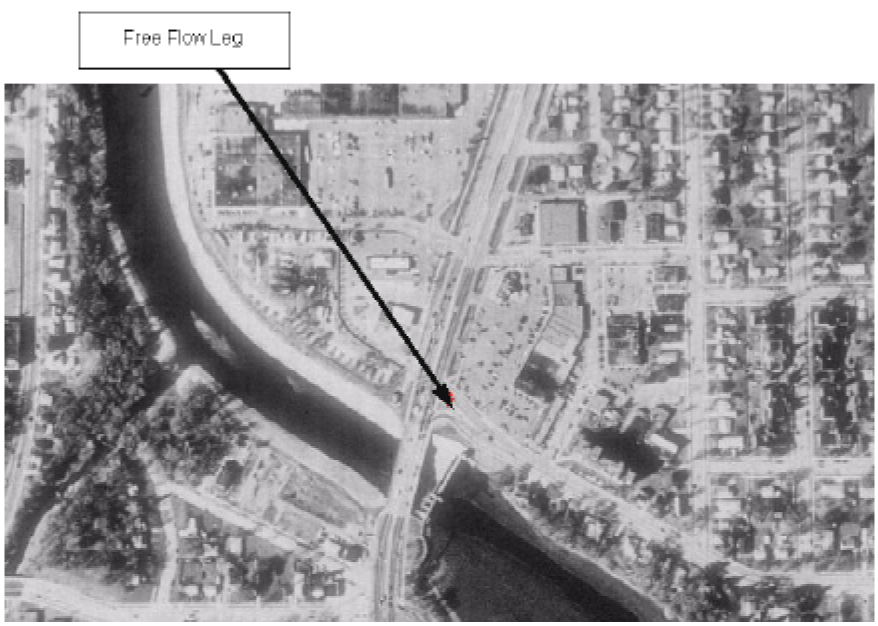
Source: [10]

Figure 4.3. Aerial view of Intersection 2.

4.1.3. Intersection 3

Intersection 3 is the intersection of 14th Street NE and Broadway (TH 63) in Rochester, MN, which is shown in Figure 4.4 and Figure 4.5.

Figure 4.4. A westbound view of Intersection 3.



Source: [10]

Figure 4.5. An aerial view of Intersection 3.

4.1.4. Intersection 4

Intersection 4 is the intersection of Civic Center Dr NW-NE and N. Broadway (TH 63) in Rochester, MN (Figure 4.6 and Figure 4.7).

Figure 4.6. A southbound view of Intersection 4.

Source: [10]

Figure 4.7. An aerial view of Intersection 4.

4.1.5. Intersection 5

Intersection 5 is the intersection of Civic Center Drive and 4th Ave NW in Rochester, MN (Figure 4.8 and Figure 4.9).

Figure 4.8. A northbound view of Intersection 5.

Source: [10]

Figure 4.9. An aerial view of Intersection 5.

4.1.6. Intersection 6

Intersection 6 is the intersection of CSAH 22 (37th St NE- E Circle Dr NE) and N. Broadway (TH 63) in Rochester, MN (Figure 4.10 and Figure 4.11).

Figure 4.10. A westbound view of Intersection 6.

Source: [10]

Figure 4.11. Aerial view of Intersection 6.

Chapter 5
The Recording of the Video at the Six Selected Intersections in the Field

Some of the intersections were unobtrusively and remotely monitored, and hours of video footage was obtained to determine the most suitable intersection for a countermeasure implementation and performance evaluation.

5.1. Procedure

Video surveillance was used to record pedestrian and driver behavior at the six selected intersections. The videos were then analyzed using an event matching procedure which will also be used to determine the effectiveness of countermeasure to improve pedestrian safety in the free flow leg in the second phase of this research study. In cooperation with the city traffic engineer of Rochester, MN, the existing traffic controllers' video footage was recorded for intersections 1, 2 and 4. When the existing controllers' video footage was not available or suitable, wireless cameras were used. The wireless cameras were attached to the traffic control masts with the help and guidance of city traffic engineers from the city of Rochester.

5.2. Equipment

A wireless four-channel video recording system was developed to capture the behavior of pedestrians and drivers at intersections with free flow legs in an otherwise unaltered traffic environment. The system needed to be versatile and robust to adapt to different weather conditions as well as the variation in intersection type and the surrounding area. Accordingly, a system was developed consisting of black and white video cameras, an FM video transmitter, a power system, an FM video receiver set, and a four-channel digital video recorder. When the traffic controlling cameras were available, not all components of the systems were needed. The assembly of the system with the traffic controller video cameras is shown in Figure 5.1. When the traffic controlling cameras were not available, wireless video cameras were used as shown in Figure 5.2.

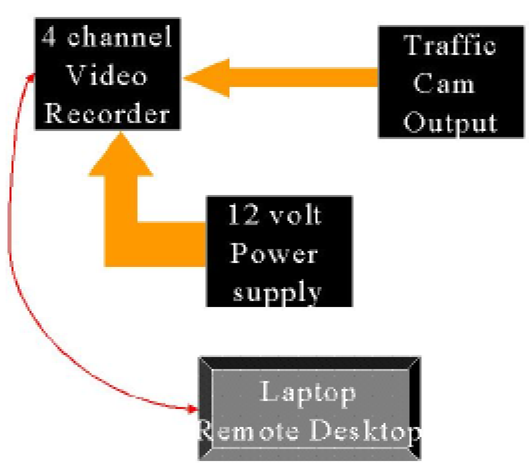


Figure 5.1. Video recording system with traffic controller input.

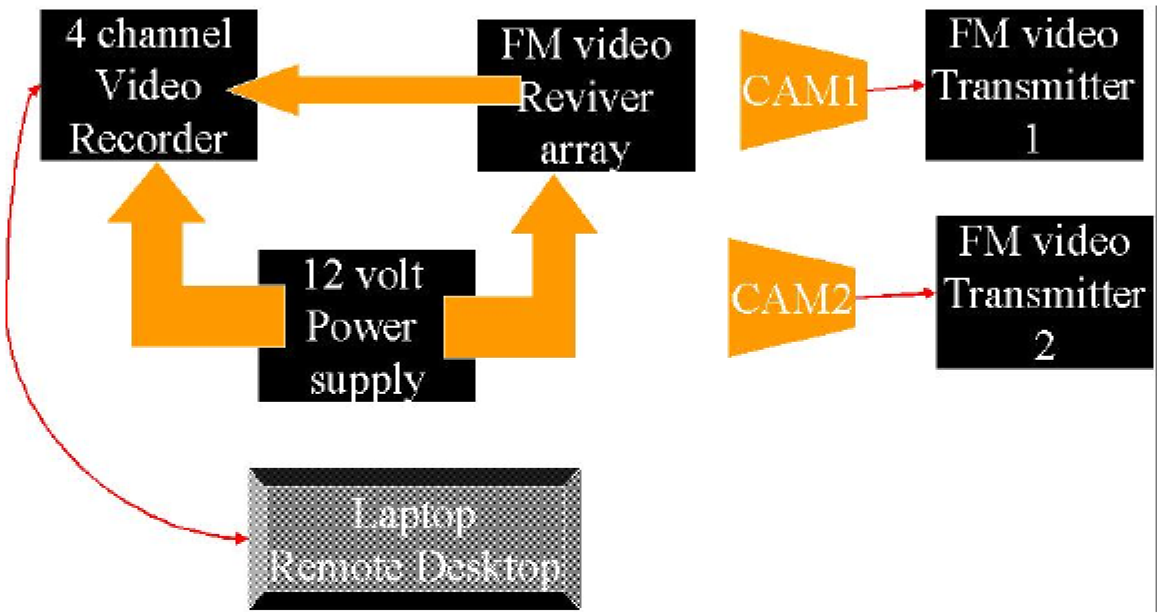


Figure 5.2. Video recording system with wireless camera input.

5.2.1. Video Cameras

The cameras used in this system needed to be highly versatile and robust for field deployment. The cameras selected were PC-106C Weatherproof C-mount Monochrome Video Security Cameras. The cold soak tests showed that there was no significant change in camera resolution at temperatures as low as -2^{0}F (-19^{0}C). These cameras were selected because they were waterproof and could withstand rapid changes in the climate and were also black and white. Using a black and white camera was important because of the performance and cost. In terms of spectral density, roughly 15% of the National Television System Committee (NTSC) signal carries the chromance information. Thus, utilizing black and white cameras reduce bandwidth requirements for video recording and signal transmission. The PC-106C camera is shown in Figure 5.3.

Figure 5.3. PC-106C camera used for wireless video recording.

5.2.2. Power System

Due to the uncertainty about the availability of electricity in the field; a battery power system was developed. A battery power system allowed for quick setups and an easy system recovery. The consumption of the transmitters and cameras was 300 mA. A 20-amp hour battery provided approximately 66 hours of video, which was plenty for traffic recording purposes. Figure 5.4 shows the power supply for the wireless system.

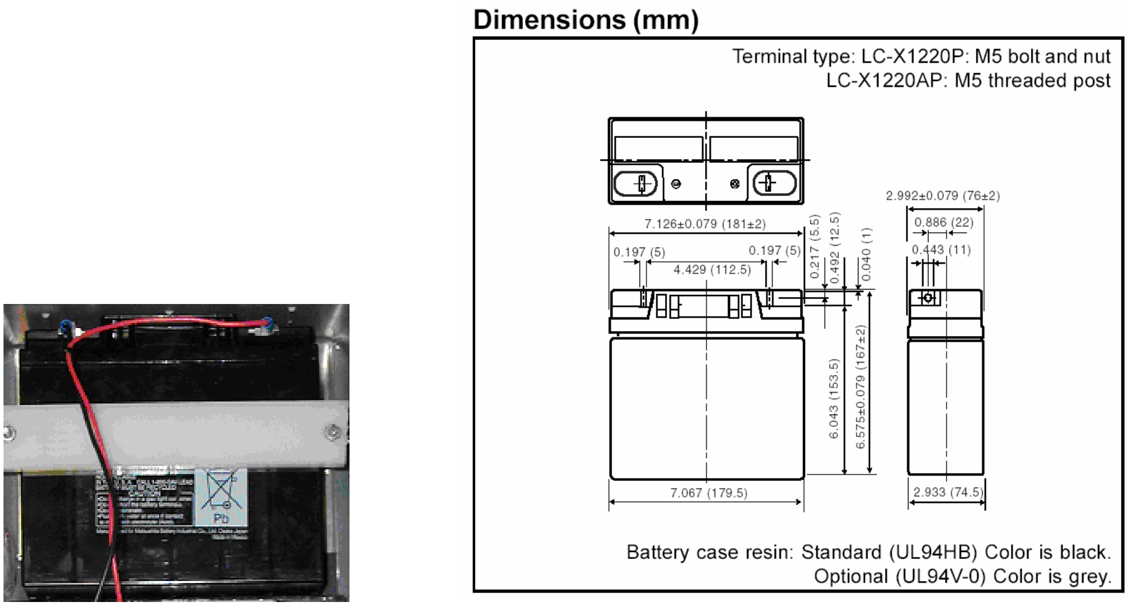
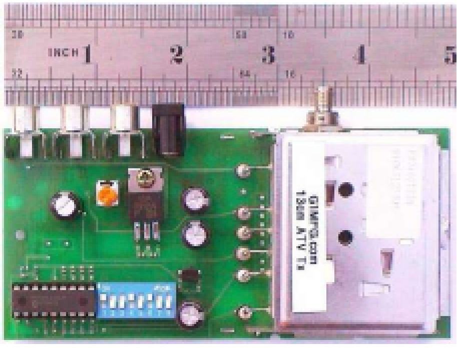


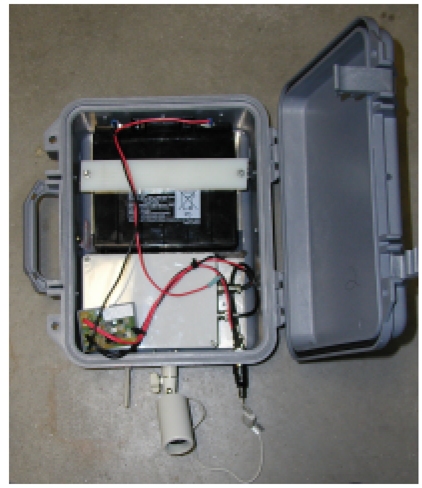
Figure 5.4. Power supply used to feed the wireless equipment.

5.2.3. Radio Transmission System

In order to transmit the signal, different products were compared and analyzed. It was determined that a form of wireless communication was necessary in order to keep the system as a set of modules as well as to maintain robustness and flexibility.

Different forms of wireless technology were examined. FM video at 2.4 Gigahertz was chosen, because of its compliance with FAR part-15. The 2.4 Gigahertz part-15 equipment is widely available, which also reduces overall cost. This system operates at previously established frequency segments and is license free. The inspection also determined that FM would suit the needs of this study beyond what AM and spread spectrum 802.11 could. Figure 5.5 and Figure 5.6 show the transmitter system and the receiver system.



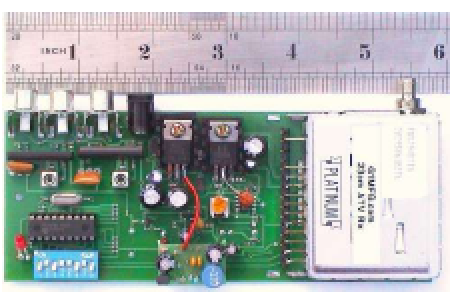


Transmitter Board

Integrated Video transmitter system

Source: [12].

Figure 5.5. Transmitter board and the integrated video transmitter system.



Receiver Board

Integrated Three Channel Receiver set

Source: [12].

Figure 5.6. Receiver board and the integrated three channel receiver set.

FM system also requires less power as compared to AM system while maintaining the quality. Furthermore, for short distances similar to those in this study, the FM system was preferable.

The generated output shows an 8 km line of site link can be established with a 4.4 dB link margin. This allows for a great margin of operation with a remote observation in an urban environment. To verify the availability of transmittance at such distances under different atmospheric conditions, the radio mobile software was used. Figure 5.7 shows a screenshot of the program at the pilot verification stage used for Iowa City downtown area, where the green line shows a strong link, and red lines show a poor link. Although not precise, an estimate of range for wireless transmission was obtained using this methodology.

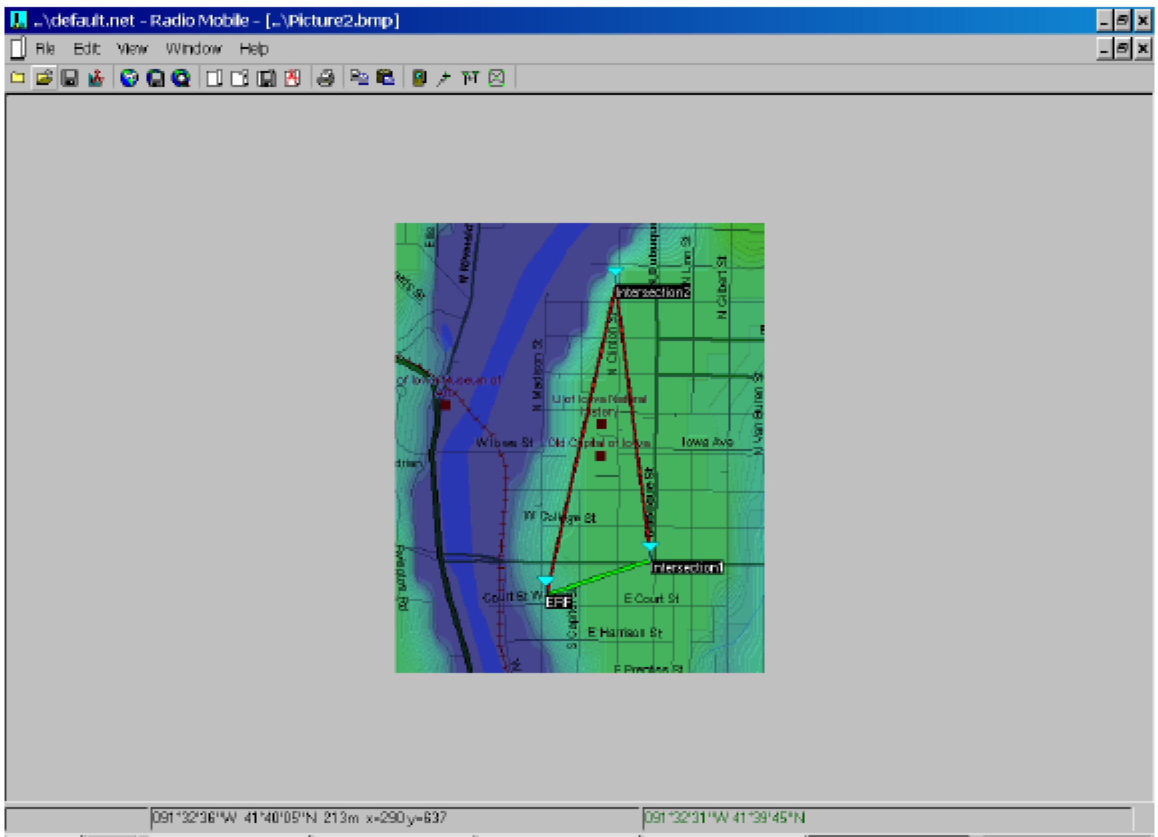


Figure 5.7. Radio mobile software.

5.2.4. Digital Video Recorder

A digital GV-800 video recorder by Digital Surveillance Systems was chosen because of its reliability in cold temperatures. This card supports 4 channels of video with sampling rates up to 30 frames per second per channel. Although the analysis of the recordings was performed manually, most video analysis software require a minimum of 8 frames per second.

Using four channels supports multiple viewing angles and multiple intersection recordings. These multiple video signals can be time stamped by the video recorder for later synchronization.

5.3. Analysis of the Video Recordings

Each recording was visually analyzed in order to determine how, potentially, the drivers and the pedestrians interacted. Several different types of conflicts were noticed in the video clips. Based on the types of conflicts in the videos, an event matching analysis technique was used to evaluate each intersection. Also based on the initial viewings of the videos, three different types of events were defined: non-events, interactions, and incidents. The three event levels are defined in Table 5.1.

Table 5.1. Events used for the analysis of the video recordings

Event Type	Definition	Possible Cases
Non-Event	There was no direct interaction between a pedestrian and a vehicle.	The pedestrian crosses the street with no approaching vehicles.
Interaction	There was a potential for conflict between a pedestrian and a vehicle.	**Case A:** The vehicle slows down, yet the pedestrian crosses the street after vehicle **Case B:** The pedestrian attempts to cross, but returns before successfully crossing the roadway. **Case C:** The vehicle stops allowing the pedestrian to cross the roadway.
Incident	There was a conflict between a pedestrian and a vehicle, with the potential for a serious injury.	Vehicles forced to swerve or stop suddenly to avoid contact with the pedestrian.

5.4. Results

Not all events fit perfectly to the definitions of any of the predetermined categories. Thus, each event was inspected independently and labeled with the most appropriate event type. The event rates are shown in Table 5.2.

Table 5.2. Event rates for each interaction

Intersection	Pedestrian Rates (pedestrians/minute)	Non-Event Rates (event/minute)	Interaction Rates (events/minute)	Incident Rates (events/minute)
1	0.012	0.006	0.000	0.000
2	0.029	0.029	0.000	0.000
3	**0.426**	**0.259**	**0.119**	**0.004**
4	0.247	0.203	0.031	0.001
5	0.165	0.108	0.043	0.011
6	0.053	0.048	0.005	0.000

5.5. Selection of the Key Intersection

Based on the event rates from the primary analysis, Intersection 3 (14th Street and Broadway) was selected as the key intersection to implement additional pedestrian safety countermeasures, and evaluate their performances. This intersection had the highest rate of crossing pedestrians. It also had the highest number of non-events, and the highest rate of interactions. Although Intersection 5 had a higher incident rate than intersection 3, due to the lower rate of pedestrian usage, it was decided that intersection 3 would provide the highest amount of data in the shortest amount of time regarding the effectiveness of selected countermeasures.

With a higher pedestrian rate, we expect to see a decreased rate of interactions and incidents at intersection 3, following the installation of the proposed safety features in the second phase of this project.

Chapter 6
Selection of a Countermeasure

6.1. Potential Countermeasures

Countermeasures within the scope of this project refer to methods with a potential to improve pedestrian safety at free-flow legs. Examples of the countermeasures include overhead crosswalk signs, pedestrians crossing signs, raised crosswalks and raised intersections, rumble strips, and new technologies recently developed for intersections. Each type of countermeasure is discussed in detail in the following section.

6.1.1. Countermeasure 1: Overhead Crosswalks Signs

Overhead crosswalk signs are located directly above the crosswalks in the middle of the lanes of traffic to be crossed. For higher driver visibility, they are often internally illuminated for nighttime use. These signs also project incandescent light downward onto the crosswalk, which also helps motorists see crossing pedestrians. The intersection studied in [7] is shown during both daylight and at nighttime hours in Figure 6.1.

Source: [7].

Figure 6.1. The use of overhead crosswalk signs at an intersection in Clearwater, FL.

Nitsburg and Knoblauch [7] compared "high visibility" crosswalks, such as the one shown above, to control locations that had no signs. The results showed that drivers were 30-40% more likely to yield to pedestrians at these "high visibility" crossings. Table 6.1 summarizes these results.

Another finding from [7] was that pedestrians were much more likely to use the crosswalks with illuminated overhead signs than crosswalks at intersections without any signs. Pedestrians were 35% more likely to cross at the “high visibility” crosswalks. The study also noted that pedestrians were not overconfident or overly aggressive at these crosswalks [7].

Table 6.1. Percentage of vehicles that stopped for pedestrians at Clearwater, FL intersection

Site No.	Site Type	Percentage of First Vehicles Stopping		
		1st Half of Crossing	2nd Half of Crossing	Both Halves of Crossing
1	Experimental: high-visibility crosswalk, refuge island	30.2%	59.5%	43.2%
2	Control: no crosswalk markings—intersection	0.0%	11.1%	2.8%
3	Experimental: high-visibility crosswalk, refuge island	39.7%	40.8%	40.3%
4	Control: standard crosswalk marking—mid-block	6.3%	53.8%	20.0%

Source: [7].

Various studies were performed in other cities around the United States to assess the effectiveness of different types of overhead crosswalk signs. Figure 6.2 illustrates some examples of these crosswalk markings.

Source: [15].

Figure 6.2. Overhead crosswalk markings for three cities. Top: Toronto, Canada, Bottom Left: Seattle, WA., Bottom Right: Tucson, AZ.

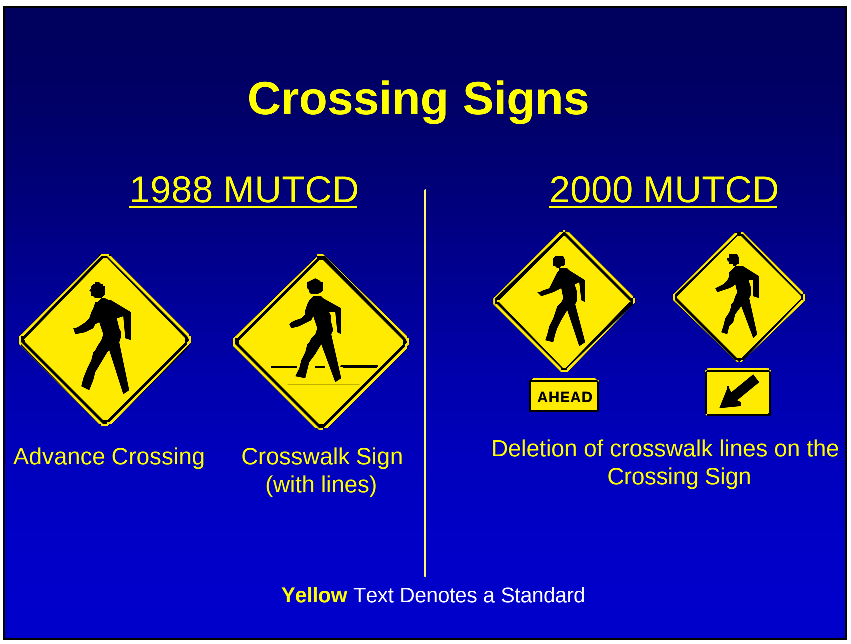
A study [15] sponsored by the Federal Highway Administration found that the overhead crosswalk signs are extremely well received in Seattle, WA. (Figure 6.2, bottom left). The city plans to continue using these crosswalk signs into the future. As of April 1999, Seattle had installed a total of 182 overhead crosswalk signs. On average, four new signs are added each year. Some of these overhead signs are accompanied by overhead flashing beacons and some are internally illuminated.

The overhead signs in Tucson, AZ, have not had the same success as those in Seattle. The signs have proved to provide little, if any, assistance to pedestrians. In Tucson, pedestrians intending to cross the intersection must activate the crosswalk sign. The study reasoned that the signs in Seattle were more beneficial to pedestrians because they are "always there" [15].

6.1.2. *Countermeasure 2: Pedestrian Crossing Signs*

Pedestrian crossing signs (W11-2) are passive signs, commonly used at crosswalks to make drivers aware of the approaching pedestrian crosswalk, and thereby the potential of crossing pedestrians. There are two types of signs that are used which are displayed in Figure 6.3. The old standards described in the MUTCD [16] are shown on the left, and the new 2000 standards on the right. The new sign with the accompanying AHEAD sign below is used in advance of a crosswalk to warn drivers of an approaching crossing. The new sign with the accompanying arrow pointing downward is used at the site of the crossing, where the arrow points the crosswalk. These signs are commonly used with other measures such as overhead crosswalk signs, raised intersections, and other countermeasures [16].

The advanced crossing signs should be placed along the right side of the roadway at a specified distance depending on the speed limit of the particular street. According to the MUTCD, an advance pedestrian crossing sign should be placed 100 feet upstream the crossing for a 30-mile per hour street. For 40 and 50 mile per hour zones, the signs should be placed 225 and 375 feet, respectively, prior to the crossing.



Source: [16].

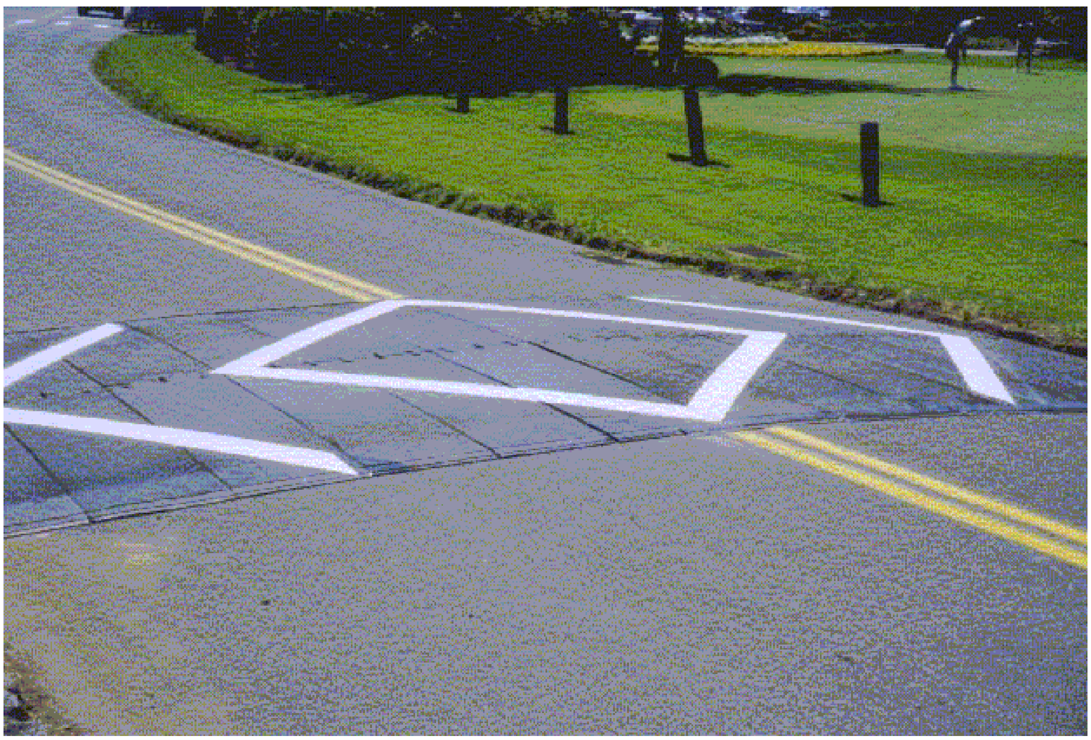
Figure 6.3. MUTCD standard crosswalk signs.

The MUTCD also specifies the crosswalk signs to be 30 inches by 30 inches in size. This manual also provides detailed dimensions for each component on these signs. The MUTCD specifies the height of the signs, as well as the distance from the roadway. In rural areas, the bottom of the sign must be at least five feet from the ground. In urban areas, the bottom of the sign must be at least seven feet from the ground. These signs should be placed at least two feet back from the edge of the roadway.

6.1.3. Countermeasure 3: Raised Crosswalks

Another safety measure to protect pedestrians from vehicle crashes is the raised crosswalk. The raised crosswalk can be incorporated into three major types of traffic calming designs: the speed hump, speed table, and raised intersections. Implementing marked crosswalks in conjunction with one of the raised roadway measures is a relatively economical alternative, while promising a reduction in pedestrian related crashes.

The first traffic calming design is the speed hump (Figure 6.4). Speed humps are rounded raised areas of pavement generally 12 to 14 feet in length. Often they are spaced 300 to 600 feet apart and are mostly used in residential settings. Typical speed hump shapes include parabolic, circular, and sinusoidal with a rise of 3 to 4 inches.



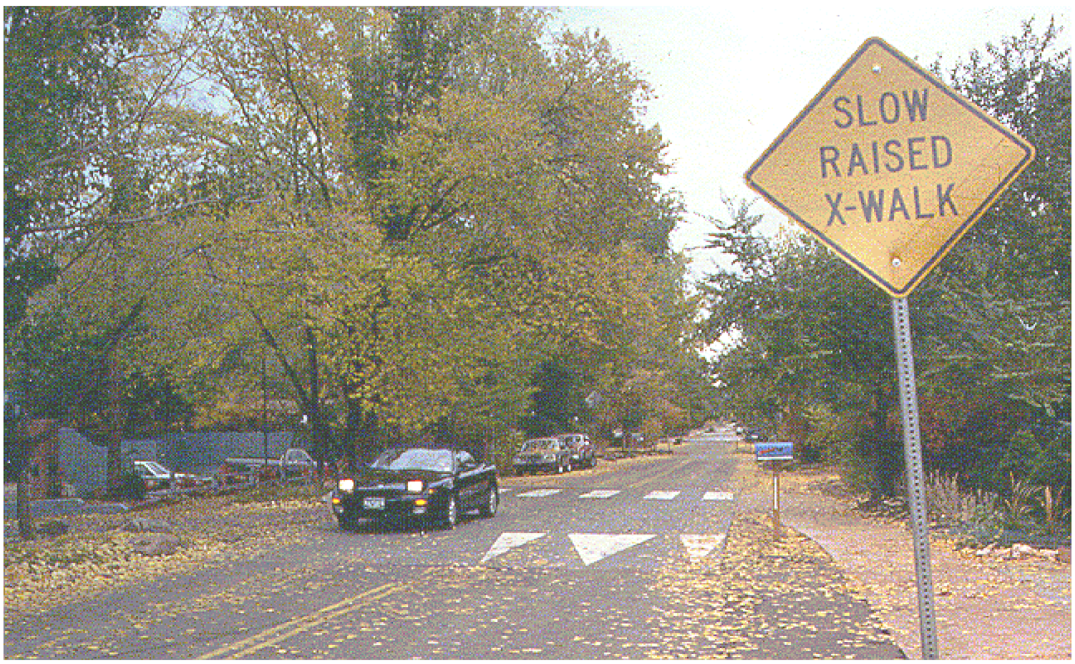
Source: [17].

Figure 6.4. A typical speed hump.

Some of the benefits resulting from [17] include a reduction of overall speed between humps of 20 to 25 percent. Also traffic studies have shown that traffic volume on streets with these humps is reduced by 18 percent and traffic accidents have been reduced by 13 percent.

Although the humps are advantageous in many ways, their use is often controversial. The speed humps are known to be difficult to construct with an average error of 1/8 inch. This could lead to unwanted jarring when traveling over such a device. Also, since a reduction of speed is needed, noise levels around these areas have increased mainly due to buses and trucks having to accelerate, which sometimes disturb close residents. Finally, one should expect an approximate delay of between 3 and 5 seconds per hump for fire trucks and up to 10 seconds for ambulance with a patient, which is an obvious safety hazard. Typically, speed humps are not to be used on emergency roads. Since speed humps do not require extensive construction or materials, the total cost is estimated to be $2000, a reasonable amount for achieving safety of pedestrians [17].

Another design used for pedestrian safety is the speed table (Figure 6.5). They are typically 22 feet long with 6 foot ramps on each end and a 10 foot flat section in the middle; other lengths of 32 and 48 feet have been reported in U.S. practice. Advantages of the speed table include a reduction in speeds, but usually to a higher crossing speed than speed humps of between 25 and 27 miles per hour. Also traffic volumes have been reduced on average by 12 percent depending on whether alternative routes are available. A reduction in accidents is noticed to be 45 percent on the average, a drastic change and a major advantage for both motorist and pedestrians. Another major advantage of speed tables is an increase in pedestrian visibility and driver conformity to yield to pedestrians [18].



Source: [17].

Figure 6.5. A typical speed table.

One disadvantage of the speed tables is a reduction in speed for emergency vehicles. Therefore the tables are not recommended for emergency routes. The overall cost of installation of a speed table is $2500. With extra brick or a crosswalk, the cost will go up but still remains quite acceptable.

The final design is the raised intersection (Figure 6.6). This countermeasure is essentially a speed table but it covers the area of the entire intersection. Construction involves elevating the entire intersection to the level of the sidewalk and providing ramps on each side. Crosswalks are placed transversally on the flat portion, usually 10-15 feet long. Raised intersections encourage motorists to yield to pedestrians. Ewing [18] suggests a rise in pedestrian yielding rates from 10 percent before the raised intersection to 55 percent after construction. A reduction in mid-block speeds was noticed to be typically less than 10 percent. The raised intersection design should not be used if sight distance is limited or if the street is an emergency route. A typical delay is 15 seconds for emergency vehicles. Since the entire intersection must be raised, the overall cost of such a project is estimated to be between $15,000 and $50,000 [18]. However, the increased cost is mitigated by the superior pedestrian safety rates and overall traffic calming ability.

Source: [17].

Figure 6.6. A typical raised intersection.

6.1.4. Countermeasure 4: Rumble Strips

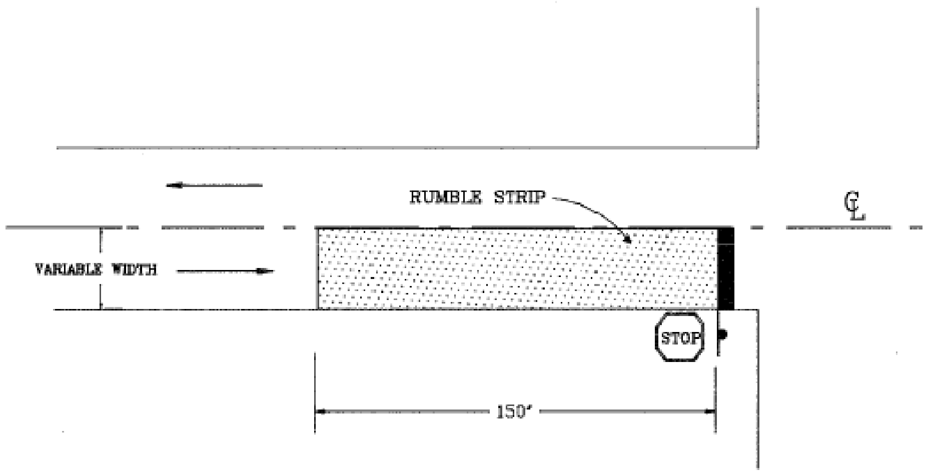
Rumble strips are grooved or raised pavement corrugations placed transversally across the full width of a roadway. The main purpose is to haptically alert inattentive drivers of an approaching change in the roadway state and restore situation awareness well in advance. They have been used from time to time on approaches to stop-sign controlled intersections, upstream the high-accident signalized intersections, on approaches to work zone environments, and along shoulders. Figure 6.7 shows a picture of rumple strips on a two-lane road.

Source: Picture taken at the intersection of North Liberty Road and Highway 965, North Liberty, Iowa.

Figure 6.7. Rumble strips.

The patterns may be designed to produce either a sporadic or a continuous rumble. The basic theory behind rumble strips is that a stronger and more rapid driver reaction results from a combination of both audible and physical stimuli, because they differ from the usual visual stimulus. The noise and vibration could vary substantially depending on type and spacing between the corrugations. Research has shown that continuous rumble strip patterns are not economical. Rather than providing a single stimulus and sensation, intermittent patterns provide a series of stimuli or changes in sensation and are more effective, more durable, and cheaper [20].

In practice, the height of raised bars varies from 1/4 inch to 3/4 inch, and the width from 6 to 12 inches. Center-to-center spacing ranges from 9 to 65 inches [20]. There are basically two types of on-road rumble strips: continuous and intermittent. Over the past three decades, different rumble strip designs were tested. The tests show that the longer the continuous rumble strips, the more effective they are in increasing driver compliance with the stop signs and in reducing accidents at stop-sign controlled intersections. However, there were indications that the longer rumble strips were distracting to drivers and caused some drivers to have difficulty with braking. In addition, there was an indication that in some cases, rumble strips were too close to the intersections.



Source: [19].

Figure 6.8. Rumble strip before a stop sign controlled intersection.

Intermittent rumble strip patterns progressed from designs using evenly sized and spaced strips to designs having variable sizes and spacing. In addition to developing intermittent patterns for rumble strips, highway agencies also began to install the strips farther upstream from the stop-sign controlled intersections. Thus, not only were drivers provided with timely stimulus by the strips, but also a more economical use of materials was achieved.

The most significant of the intermittent designs was developed by the Contra Costa County Highway Department in California and later used with some variations by at least six other agencies [21]. The Contra Costa County practice became an accepted standard for the long intermittent pattern, and began a trend toward an orderly variation in the size and spacing of strips. The design consisted of patterns approximately 1000-foot long. The individual strips were most often 25 feet long, although for some installations the lengths have ranged from 15 to 30 feet. They were spaced at 100-foot intervals for the first half of the pattern and 50-foot intervals for the other half. Most variations on these patterns have differed only in total length, with individual strips added or deleted according to conditions of approach speed, geometry, etc. All agencies that evaluated the Contra Costa County design reported success. The measure of effectiveness that had been considered included changes in speed and deceleration patterns, effects on accident history, and driver observance of stop controls [21].

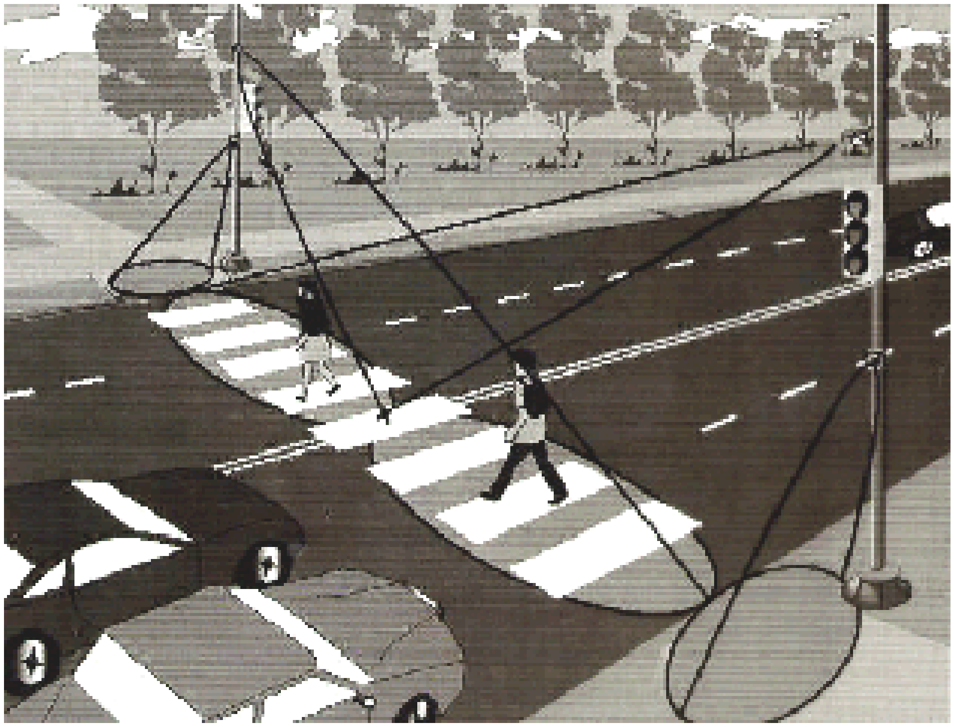
Research has shown that continuous rumble strip patterns are not economical, could be mistaken for poor pavement sections, and are less effective than the intermittent patterns. Rather than providing a single stimulus and sensation, intermittent patterns provide a series of stimuli or changes in sensation and are more effective and durable. On-road rumble strips have been used, for the most part, as permanent installations in advance of hazardous locations, but only when the roadway conditions presented undesirable physical or geometric constraints. Furthermore, rumble strips are generally used only after suitable standard traffic control devices fail to resolve a problem satisfactorily. Because of the infrequency of such cases, the use of rumble strips is rare, and therefore, very little is known about the effectiveness and drawbacks of various kinds of designs. Temporary applications of rumble strips have not become a standard practice because of continuing concerns with proper design, maintenance, liability, noise, car handling, and a lack of sufficient supportive research on durability, effectiveness, and driver behavior. There is a need for further research on rumble strips.

6.1.5. Countermeasure 5: Crosswalk Technologies

In two studies conducted by the Federal Highway Association, different crosswalk technologies were implemented to assess their effectiveness. Both studies involved the improvement of the push-button pedestrian walk signal. Improvement is needed with this type of cross-walk, because although it is an effective measure to reduce the number of pedestrian and car conflicts, studies show that less than half of pedestrians actually use the buttons. The first study conducted in Los Angeles, CA, Phoenix, AZ, and Rochester, NY tested the effects of microwave and infrared object sensors that auto-activate the pedestrian crosswalks at various intersections.

These sensors were positioned to monitor zones of various shapes and sizes, which were subject to the type of sensor and its positioning in relation to the intersection. The sensors can be programmed to only detect an object if it stays in the detection zone for a minimum amount of time. This measure helps to reduce the number of false alarms triggered by objects or persons passing through the detection zone. The sensors in this study were implemented in addition to the pre-existing push-button pedestrian walk signal and were tested against intersections containing only the push-button signal. The results of the study have similar results to the use of the push button device; there was a 24 percent increase in the number of pedestrians who began to cross during the walk signal. In addition, there was an 81 percent decrease overall in the pedestrians who began to cross during the steady Don't Walk signal.

A second measure was the illuminated pedestrian push buttons (Figure 6.9 and Figure 6.10), which light after being pressed by the pedestrian. In the past, pedestrians have been less likely to wait for the walk signal because they are uncertain whether they in fact activated the sequence, as there is no feedback after the button is pushed. To this effect, researchers designed a button, which provides feedback to the pedestrian, indicating that the crosswalk system has received the signal initiated by the user. Although the pedestrians didn't tend to use the illuminated pedestrian push buttons more, the researchers hope that the light will encourage the pedestrian to wait for the Walk signal before crossing the intersection. Though no short term-effects were noted, the researchers are hopeful that the long-term effects will prove to be a success in avoiding conflicts between cars and pedestrians.



Source: [22].

Figure 6.9. An illuminated crosswalk.

Source: Federal Highway Administration.

Figure 6.10. Pedestrian push buttons.

6.2. Sensor Activated In-ground and In-Sign LED Crosswalk Systems

An emerging technology allows the use of efficient LED systems buried in either side of the crosswalk to actively warn the drivers for the approaching crosswalk especially at night. However, in-ground LEDs are not as effective in daytime as it is in nighttime. These crosswalks are also accompanied with crosswalk signs, sometimes with in-sign LED systems. When activated both the in-sign and in-ground LEDs start flashing, and stay on for a certain amount of time.

The sensors are directionally sensitive (sensitive to inbound movements) to pedestrians as well as bicyclists, scooters, and similar objects. As soon as the sensors trigger the system, both the in-ground and in-sign LED's start flashing. The duration of the active state depends on a pre-timed setting. A typical pedestrian speed used for active state timing is 4ft/sec.

The equipment and installation costs depend on the installation site characteristics such as the length of the crosswalk. Installation on an average 24ft crosswalk may cost around $35,000.

The in-ground LEDs are known to be self-cleaning, and resistant to snow and dust. The system is also snow-plowable. This crosswalk system allows the vehicle traffic to flow, but conspicuously alert drivers when there is a pedestrian using the crosswalk. Thus, this active crosswalk system seems beneficial from both traffic flow and pedestrian safety points of view. Figure 6.11 shows an illustration of in-ground LEDs. Figure 6.12 shows a pilot application of the system in Iowa City, IA.

Figure 6.11. In ground LEDs on crosswalk.

Figure 6.12. An in-ground and in-sign flashing LED crosswalk application in Iowa City, IA.

Chapter 7
Discussion and Recommendations

Pedestrian injuries and fatalities in free-flow legs seem to originate from an ambiguity of the priorities, and a misinterpretation of the intended system principles. Drivers do not expect to see pedestrians on free flow legs, and pedestrians exercise their right-of-way while assuming that drivers are aware of them and their expected behavior. Thus, the solution should incorporate educating the drivers by simply warning them about the existence of pedestrians in free-flow legs, while maintaining the free-flow functionality for vehicle traffic.

A set of pedestrian safety measures applicable to free-flow leg crosswalks was identified through an exhaustive literature review, an online survey, and in-the-field free-flow leg traffic recordings. Detailed reviews of each alternative with associated pros and cons were determined. Most economical solutions are passive speed-reducing measures, which may cause permanent changes in the roadway structure for most practical purposes. We believe that such measures would be counterproductive from a free-flow point of view, because they slow the traffic regardless, even in the absence of pedestrians.

Solutions that do not require changes in the roadway structure include internally-illuminated overhead crosswalk signs, and sensor activated in-ground and in-sign LEDs. These systems do not force drivers to slow down, but rather warn them. Internally-illuminated overhead crosswalk signs are passive warning systems that increase pedestrian visibility and indicate the possibility of crossing pedestrians (since it is not active). The infrared sensor-activated flashing in-ground and in-sign LEDs is a newer technology that features an active warning system. This active warning system indicates an almost certain real-time existence of pedestrians in a conspicuous fashion. Flashing lights are also known to capture and reorient visual attention much successfully than steady lights [23][24][25].

Six intersections with free flow legs were monitored in the Olmsted County area in Minnesota for a total of 40 hours with video cameras. Based on our analysis, among those monitored, intersection 3 (details of which are given in section 4.1.3 starting on page 17) is selected as the key site. This site has the highest pedestrian traffic volumes and pedestrian-vehicle conflicts, which promises a fast yet effective evaluation of the selected countermeasure.

Our research team suggests the implementation of a sensor activated in-ground and in-sign LEDs crosswalk system on the selected free-flow leg (Intersection 3: 14th Street NE and Broadway (TH 63) in Rochester, MN). Further monitoring of the intersection *before* and *after* the implementation of the selected countermeasure will provide the grounds for assessing the effectiveness of the selected countermeasure.

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Appendix A
Online Survey and Survey Results

University Of Iowa Operator Performance Lab (OPL)
Minnesota Department of Transportation (Mn/DOT) Study

Slip Lane Survey

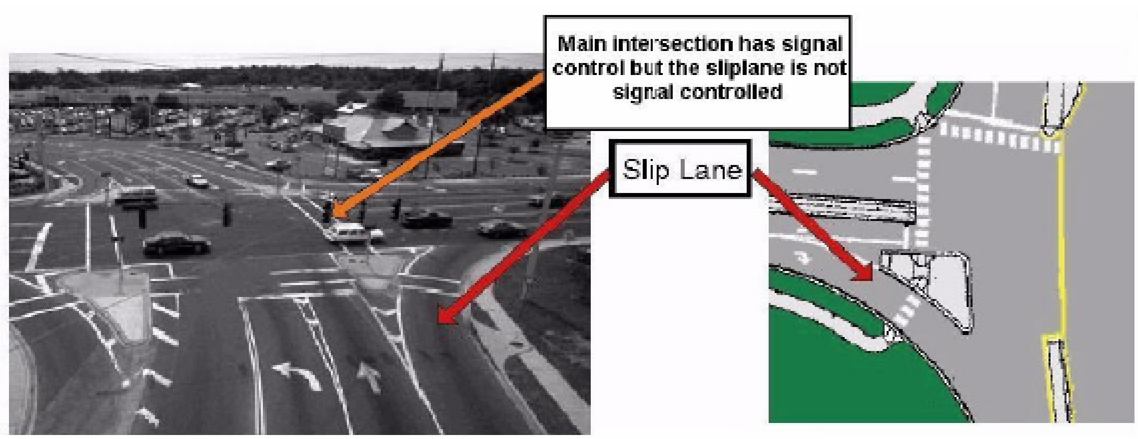
Introduction

Dear Survey Respondent:

Thank you very much for taking the time to participate in this important survey. You have been chosen to participate in this survey because of your expertise as a traffic engineer or a transportation infrastructure professional. Currently, the Operator Performance Laboratory (OPL) of the University of Iowa and the Minnesota Department of Transportation (Mn/DOT), in conjunction with the Minnesota Local Road Research Board are conducting a research study on slip lane intersections. The goal of this research is to provide Minnesota Department of Transportation with a set of design measures to improve pedestrian safety at intersections with slip lanes by modifying driver behavior in a positive way.

Your answers will help us obtain information about slip lane intersection design measures practiced in your state. The results of this survey will be used to develop a report of practices as they relate to improving pedestrian and driver safety.

Slip lanes increase traffic flow by allowing right turning traffic to continue through the intersection without having to stop for a red light. The slip lane's main function is to increase traffic throughput. We would like to know how this affects pedestrian safety. Hopefully it can be determined if there are measures that can be added to the design to improve overall safety. In particular we are interested in finding out how your agency designs slip lane intersections from a pedestrian safety point of view. We would like to know what sort of design features, traffic control devices, and technology you use, if any, to safely integrate pedestrian traffic with vehicle traffic in slip lane intersections. This figure shows a picture and a diagram illustrating a free right intersection



Please read the following instructions carefully and answer all of the questions to the best of your knowledge as a traffic engineer or a transportation infrastructure professional in your agency. Please feel free to forward this URL address to other individuals in your agency so they may complete this questionnaire as well. If you feel that you are not able or willing to answer the questions in this survey, we would appreciate it if you could forward the URL address to a person or to persons who you consider to be qualified.

The questionnaire contains multiple-choice questions, as well as a comment box, in which you can specify any related information. Each question has instructions on whether you may check more than one checkbox. There are no right or wrong answers. We are solely interested in the practices and experiences of your agency as they relate to slip lane intersection design. Please read each question carefully and do not hesitate to make any comments about any of the questions in the associated comment boxes. After completing the questionnaire, click on the Submit button to finish the survey.

Completing the questionnaire is estimated to take no more than 15 minutes. Upon completion, please click on the submit button to send your answers. We appreciate it very much that you are taking your time to complete this questionnaire.

I. Respondent Information

Please complete the requested information in the space provided.

Name: Agency:

City: State or County or Province:

Job Title:

Primary Job Responsibilities:

Years of Service:

May we contact you to get further information and clarifications if the information provided by you needs further elaboration? (Check one)

Yes

Phone: E-mail:

No

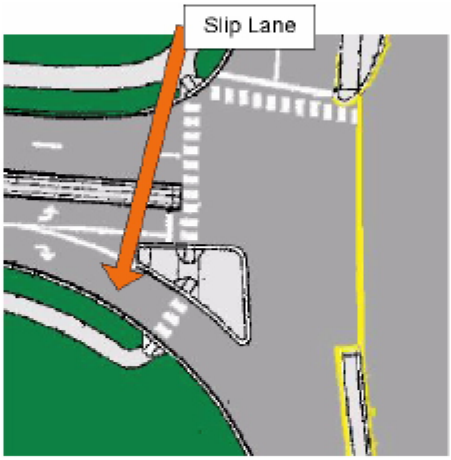
If you are not the best person to contact, can you refer us to someone who is better suited to answer related questions? (Please specify contact information of person(s))

Name:

Phone: E-mail:

II. Slip-Lane Intersection

1. Are there any slip lane intersections in your jurisdiction? (Check One)



Yes No I do not know

Comments:

If YES, continue, if NO, SUBMIT.

2. Do you use a local, state, or national standard or design guide for slip lane intersection design? (*Check One*)

Yes, please specify the standard:

No

Other, please specify

I do not know

Comments:

3. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a vehicle traffic flow point of view? (*Check One*)

Yes

No

Other, please specify

I do not know

Please elaborate on your choice:

4. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a pedestrian traffic flow point of view? (*Check One*)

Yes

No

Other, please specify

I do not know

Please elaborate on your choice:

5. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a vehicle safety point of view? (*Check One*)

Yes

No

Other, please specify

I do not know

Please elaborate on your choice:

6. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a pedestrian safety point of view? (*Check One*)

Yes

No

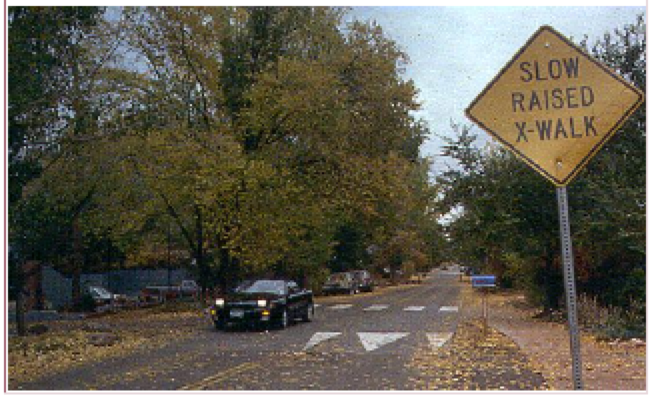
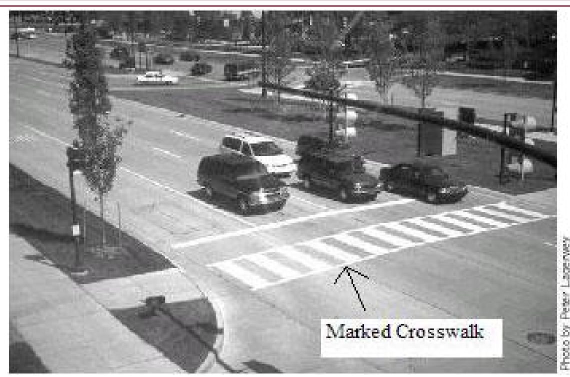
Other, please specify

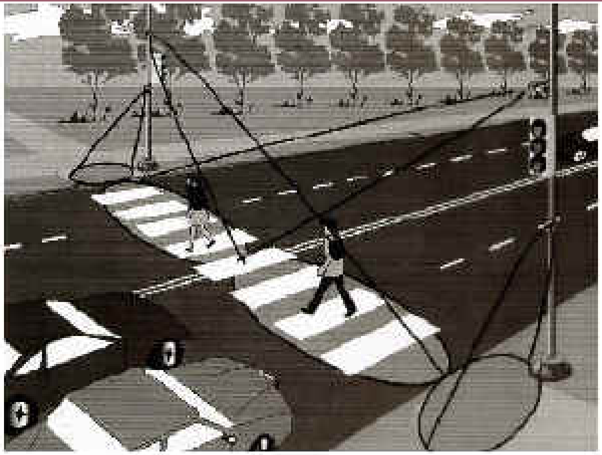
I do not know

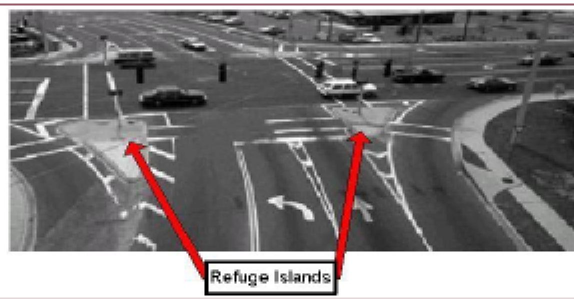
Please elaborate on your choice:

7. Do you use (or have used in the past) the following devices in your jurisdiction? If you do, please rate the effectiveness of each device that is in use in your area. (*Check all that apply*)

		Ever Implemented?			**Rate of Effectiveness**				
		YES	**NO**	**Don't Know**	**1= Poor 5 = Excellent**				
Overhead Crosswalk Signs		Yes ☐	No ☐	Don't know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5
Pedestrian Crossing Signs		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5

Raised Crosswalk		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5
Speed Hump/Table		Yes ☐	No ☐	Don't K now ☑	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5
Distinguishable pavement markings, such as zebra stripes		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5

Rumble Strips		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5
Active Warning Devices when Pedestrians are Present		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5

Pedestrian Push Button/ Activated Device that warns driver of crossing pedestrian in Slip Lanes		Yes	No	Don't Know	Poor 1	2	3	4	Excellent 5
Refuge Islands		Yes	No	Don't Know	Poor 1	2	3	4	Excellent 5

Flashing beacon when pedestrians are present		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5
In ground LED's on crosswalk		Yes ☐	No ☐	Don't Know ☐	Poor ☐ 1	☐ 2	☐ 3	☐ 4	Excellent ☐ 5

Please describe any other traffic control devices and /or other design suggestions:

8. Approximately how many slip lane intersections are present in your area? Please fill in the following values.

Number of slip lane intersections in my jurisdiction:

Representing approximately ……% of the total number of intersections in my jurisdiction.

Comments:

9. Do you monitor and/or record vehicle-pedestrian interactions in slip lanes? (Check One)

Yes

└── Please explain briefly how you document these interactions:

No

Other, please specify:

I do not know

10. Do you have any vehicle-pedestrian accident records for the slip lane intersections in your jurisdiction? (Check One)

Yes

└── Please specify if and how we can obtain these records:

No

Other, please specify

I do not know

Please elaborate on your choice:

11. If you can provide any relevant information (for example, studies, reports, or guidelines) pertaining to this survey, please respond below.

Comments:

SUBMIT

Table A.1. Summary of questionnaire responses.

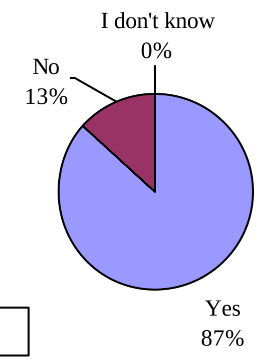
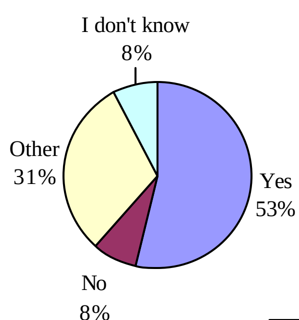
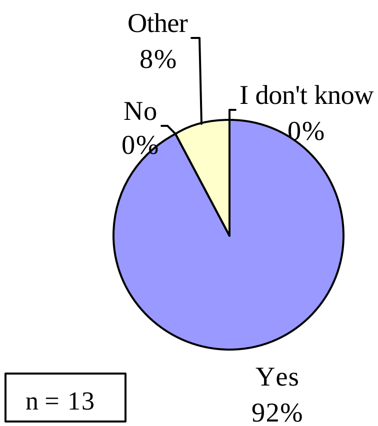
1. **Are there any slip lane intersections in your jurisdiction?**	
 n = 15	• The type shown in the photo is controlled by a yield sign. • Not very common though.
2. Do you use a local, state, or national standard or design guide for slip lane intersection design?	
 n = 13	• We have different type of slip lanes. Where it is a true slip ramp we follow AASHTO, for dedicated right-turn lanes or slip lanes we use City standards. • We use Caltrans (State) Traffic Manual and Highway Design Manual. • Bureau of Design and Environment Policy Manual (Illinois), Manual on Uniform Traffic Control Devices. • Our slip lane normally is a free flow where it has own lane to merge in. • We use Transportation Association of Canada - Geometric Design Guide for Canadian Roads. Where pedestrians are present, small refuge islands and speed controlling curves on the slip lanes are used. Design vehicle also has design influence. • We use AASHTO and State Design Manual. • Combination of standards to fit conditions. We typically use AASHTO standards as a starting point and also refer to Oregon DOT standards and try to achieve the best possible design for the conditions. • Combination of AASHTO Green Book and State of Wyoming Standard. We design each one to fit the individual intersection. Therefore, it's a little tough to say that we use any one standard.

Table A.1 Continued.

3. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a <u>vehicle traffic flow</u> point of view?



- They increase traffic flow.
- Obviously they help right turning traffic.
- Yes, if the downstream merge is adequate.
- As long it has its own lane to merge to.
- Especially with moderate to high right turn volumes, removing right turn vehicles from signal control improves overall intersection level of service significantly. The slip lane continuing in its own lane after the turn is preferable. Large pedestrian volumes will have an adverse effect on the right turn efficiency.
- Dependent upon right turn demand volume.
- By removing the right turn vehicles from the queue, I can increase intersection capacity.
- It's appropriate to consider the use if there is a high volume of right turns and limited pedestrian conflict.
- Provided certain design elements can be accommodated. The big ones we look at are adequate sight distance and adequate acceleration and deceleration lanes.

Table A.1 Continued.

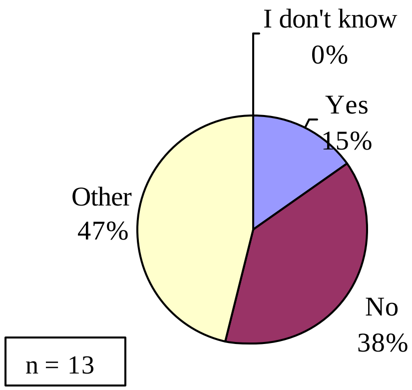
4. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a <u>pedestrian traffic flow</u> point of view?	
	• We use yield signs to help with pedestrians crossing. • Depends on the amount of vehicular traffic. If high ped areas, pedestrians can take over the crosswalk, while in high traffic areas pedestrians may have a harder time circulating. • Pedestrians are forced to cross the slip lane at a point where drivers are preparing to merge. • I don't see any significant advantage or disadvantage to ped flow. • Normally it is not pedestrian friendly also in our state we try to get rid of them and bring it to the intersection. This of course depends on the traffic volume. • We prefer short crossing segments. Pedestrian Actuated Signals are used within the intersection box only. • Probably not the best choice in most cases, but works acceptably in many cases. • Not the primary controlling factor for intersection design. • I don't think they compromise pedestrian safety as long as sight lines are acceptable and the geometry requires the right turning vehicle to slow down. I do believe there can be a pedestrian safety concern if the conditions encourage the right turning vehicle operator to be looking back for conflicting traffic from the left when there is a pedestrian in front of the vehicle. I am also aware of the accessibility issue raised by/for visually impaired pedestrians and recognize that slip lanes would not provide an audible clue to those pedestrians. • Motorists tend to be aggressive and don't always yield to pedestrians. And, motorists are not always looking to the right for pedestrians, they are more likely to be concerned about the merge condition and looking to the left, putting pedestrians in jeopardy. • Accommodating ADA requirements into intersection design is extremely difficult. • We have experienced several accidents with the free right and we don't install it unless we are sure the pedestrian volume will be low or if we do allow it we provide a separate pedestrian facility or a ped actuated signal light for the free right which requires the right turn to stop if the pedestrian call for service. • We've done some work at trying to separate the crossing point from the yielding point. This seems to help, but not a lot.

Table A.1 Continued.

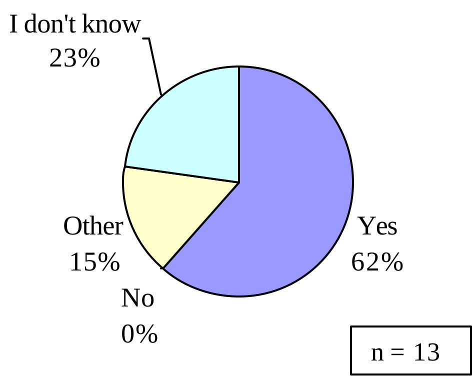
<table>
<tr><th colspan="2">5. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a <u>vehicle safety</u> point of view?</th></tr>
<tr><td>
</td><td>
• We see no disadvantages to them.
• Depends on whether drivers yield as required.
• Depends on how they are designed. In another state (to remain nameless), they frequently used slip lanes with yield signs. At the vast majority they had a long acceleration lane. After a while I became accustom the acceleration lane and started taking the slip lane without stopping. The first time I did this there was no acceleration lane and I was run off onto the shoulder. Consistent application is critical.
• Yes, under the above design only.
• Issue not studied.
• I suppose that by removing the right turn vehicles from the through traffic stream could have some increased vehicle safety. On the other hand, there could be less vehicle safety because of more rear end and side swipe accidents at the yield and merge areas.
• Deceleration and acceleration lanes get these movements out of the thru movements.
• Yes, assuming we can provide adequate sight distance and acceleration and deceleration lanes.
</td></tr>
</table>

Table A.1 Continued.

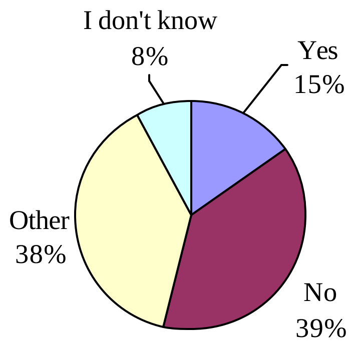
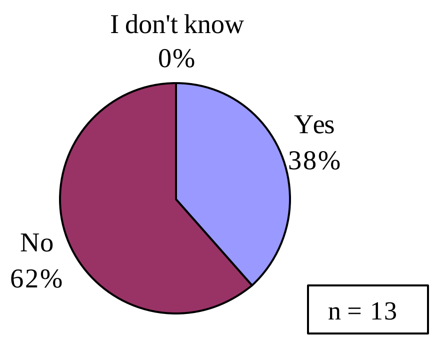
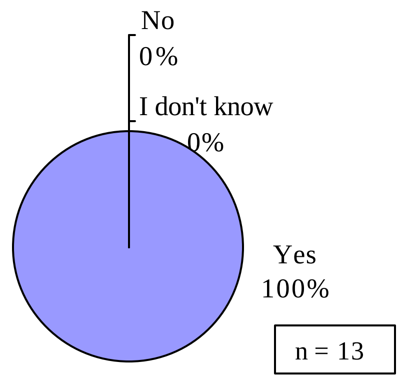
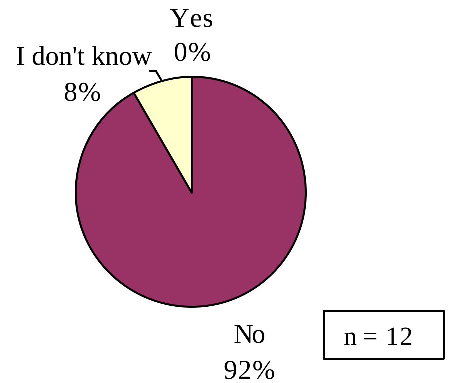
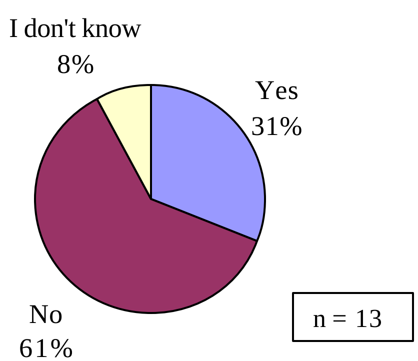
6. Based on your experience and your opinion, do you consider slip lane intersections to be an effective design from a pedestrian safety point of view?	
 n = 13	• Pedestrians complain that vehicles don't yield at crosswalk and request STOP signs or signalization, which defeat the traffic advantages. Feature speeds up vehicles, which is undesirable for pedestrians. • Depending on how pedestrians are handled they can create operational complexities (Signal controllers have some difficulties handling pedestrian signals across slip lanes) • Issue not studied. Our area of jurisdiction is primarily suburban and rural. We typically have low pedestrian volumes. • Not in all cases. Can cause problems at some locations, but works acceptably at most. • Provided a raised refuge island(s) is included. • I don't think they compromise pedestrian safety as long as sight lines are acceptable and the geometry requires the right turning vehicle to slow down. I do believe there can be a pedestrian safety concern if the conditions encourage the right turning vehicle operator to be looking back for conflicting traffic from the left when there is a pedestrian in front of the vehicle. I am also aware of the accessibility issue raised by/for visually impaired pedestrians and recognize that slip lanes would not provide an audible clue to those pedestrians. • It depends. As I mentioned above, motorists tend to be aggressive and don't always look to their right. However, having a slip lane with a raised "pork chop" island, allows for a pedestrian refuge and the ability to cross the street in segments. • Island refuge is important to make crossing distances shorter.

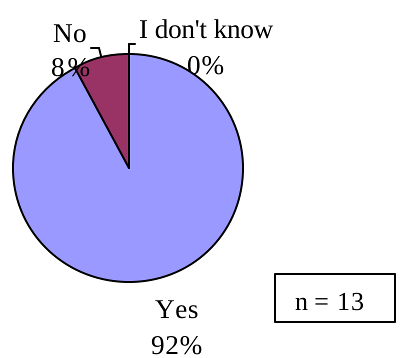
Table A.1 Continued.

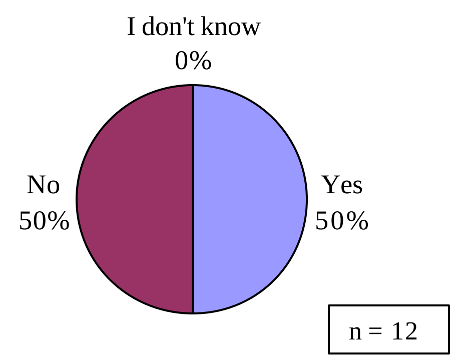
<table>
<tr><td colspan="3">7. Do you use (or have used in the past) the following devices in your jurisdiction? If you do, please rate the effectiveness (1 = poor, 5 = excellent) of each device that is in use in your area.</td></tr>
<tr>
<td>Overhead Crosswalk Signs:


Average Effectiveness = 3.3</td>
<td>Pedestrian Crossing sign:


Average Effectiveness = 3.3</td>
<td>Raised Crosswalk:


Average Effectiveness = 4</td>
</tr>
<tr>
<td>Speed Hump/Table:


Average Effectiveness = 4</td>
<td>Distinguishable Pavement Markings, such as zebra stripes


Average Effectiveness = 3.67</td>
<td>Rumble Strips


Average Effectiveness = 3.5</td>
</tr>
</table>

Table A.1 Continued.

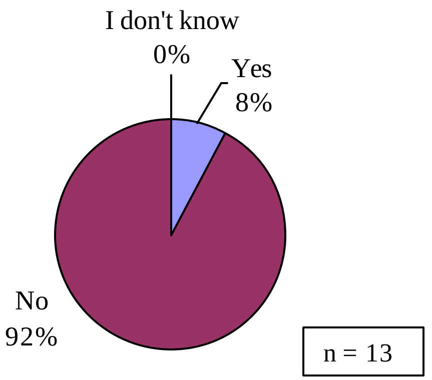
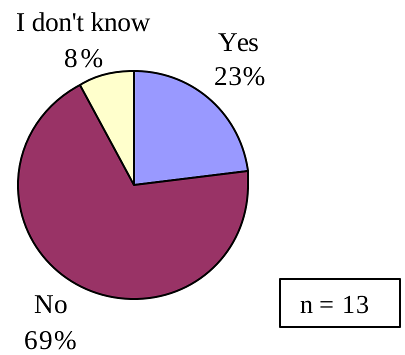
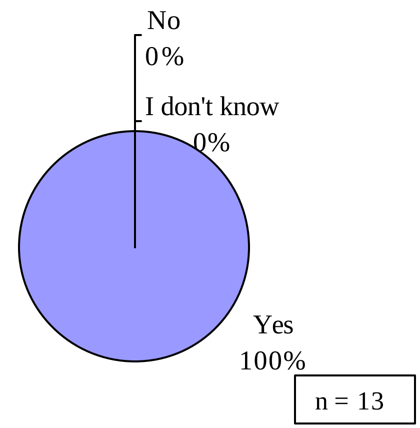
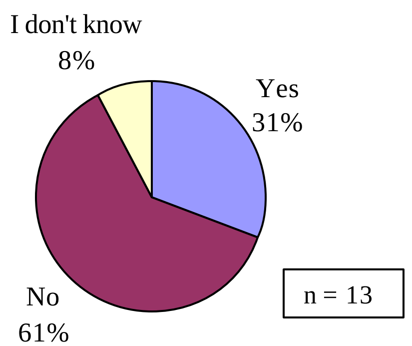
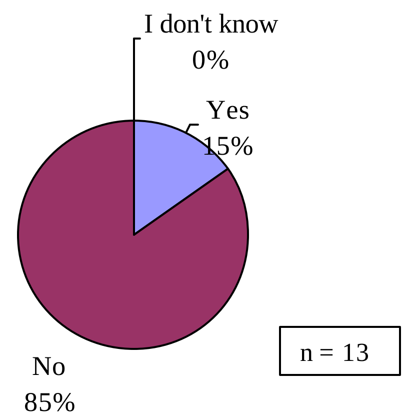
Active Warning Devices when Pedestrians are Present  Average Effectiveness = N/A	Pedestrian Push Button/ Activated Device that warns driver of crossing pedestrian in Slip Lanes  Average Effectiveness = 2.5	Refuge Islands  Average Effectiveness = 3.89
Flashing beacon when pedestrians are present  Average Effectiveness = 3.5	In ground LED's on crosswalk  Average Effectiveness = N/A	

Table A.1 Continued.

- "PED XING" advance pavement messages.
- Questions above were too open ended. In some situations the devices might be excellent in others poor. Also, many of these devices are not appropriate to the major arterials that a state agency maintains.
- At some locations the signal and markings have been modified to place the right turn under signal control. At some locations we have eliminated the slip ramp when the intersection was reconstructed. At some locations we install a yield to pedestrians sign for traffic turning right.
- Supplemental crosswalk (in road) devices.
- A comment on the flashing beacon as shown above: we don\'t use the one shown but use the traditional flashing beacons (MUTCD) which aren't very effective when it is time based or actuated by the user. Not all users will actuate the beacon and if it's time based, then it's giving a warning when none is present.

Table A.1 Continued.

8. Approximately how many slip lane intersections are present in your area?
• About 100 slip lane intersections are in my jurisdiction, representing approximately 1.5% of the total number of intersections. These are estimates only. In general very few intersections have these features, tend to be isolated to some major intersections and older designs. Most streets in the city have traditional grid intersections with tight turning radii. • About 100 slip lane intersections are in my jurisdiction, representing approximately 2% of the total number of intersections. Most are older existing intersections. Not installing new ones currently. • About 34 slip lane intersections are in my jurisdiction, representing approximately 47% of the total number of intersections. • Fairly common on older designs in urban areas. Not very common on newer designs. Most intersections in state with even moderate ped activity are not designed with slip lanes. • About 20 slip lane intersections are in my jurisdiction, representing approximately 5% of the total number of intersections. • About 14 slip lane intersections are in my jurisdiction, representing approximately 10% of the total number of intersections. We've also had one that was recently removed. I'm only counting signalized intersections.

Table A.1 Continued.

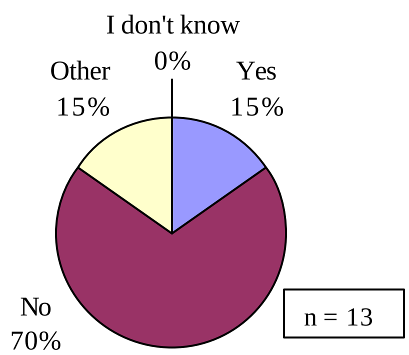
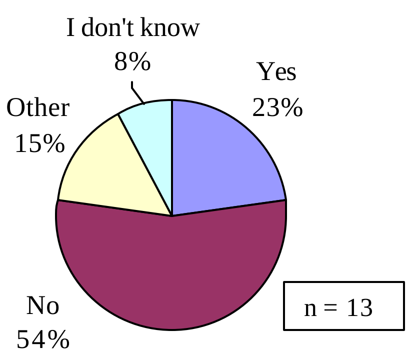
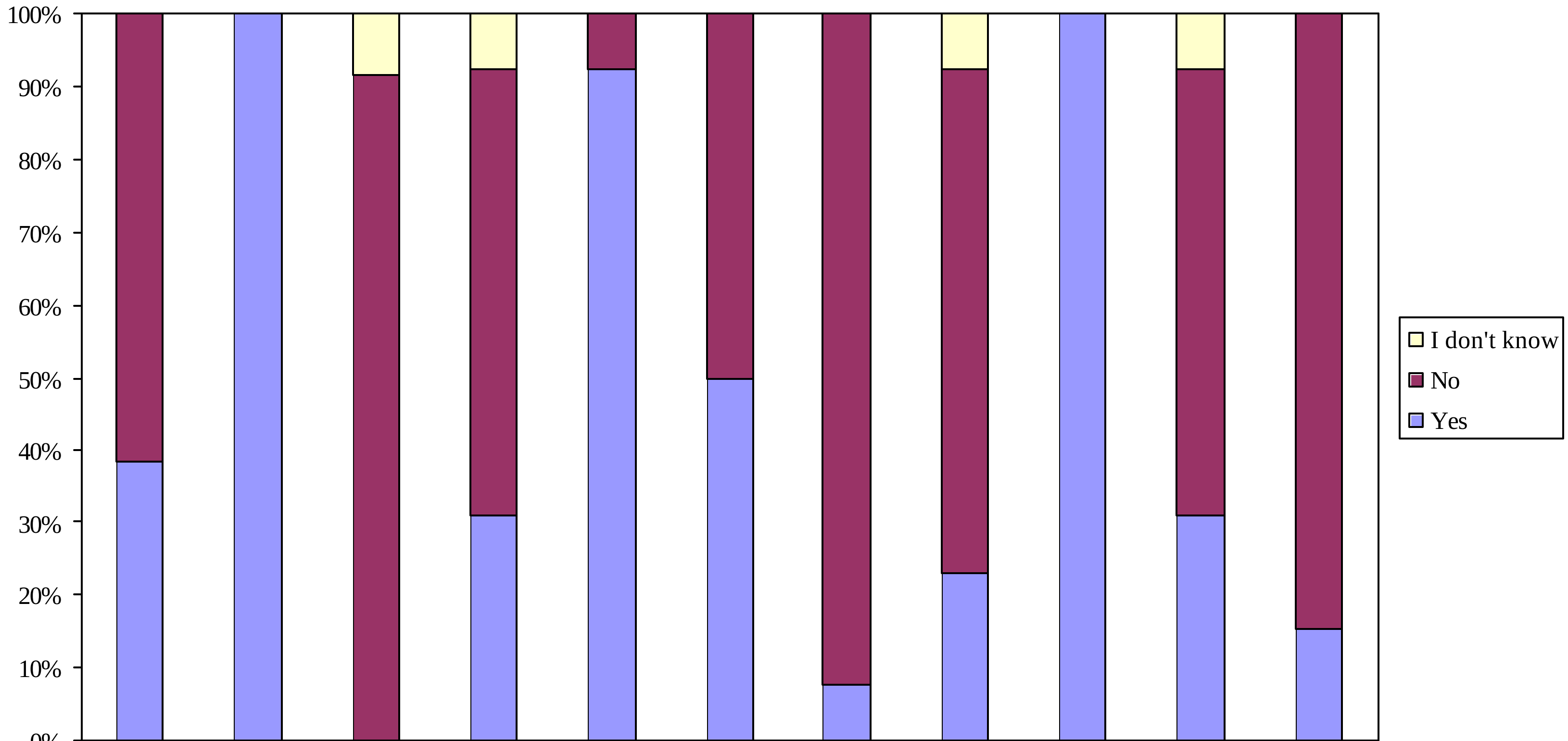
9. Do you monitor and/or record vehicle-pedestrian interactions in slip lanes?	
	• We just monitor collisions in general. • Police crash reports record them, but we don't specifically track this type of crash. • We monitor pedestrian/vehicle crashes, but not specifically at slip lanes. We do not have an inventory of intersections with slip lanes, but could search at known or potential problem locations. • We don't monitor it but we do request listing of pedestrian accidents to determine if we need to make safety improvements.
10. Do you have any vehicle-pedestrian accident records for the slip lane intersections in your jurisdiction?	
	• Get in touch with Tom Larsen, City Traffic Engineer (541) 682-4959. • Our state law does not allow us to share this information with you. You will have to request it from the ND DOT. • Yes, but they're not separated from general intersection crashes. • These are estimates only. In general very few intersections have these features, tend to be isolated to some major intersections and older designs. Most streets in the city have traditional grid intersections with tight turning radii. • Police crash reports record them, but we don't specifically track this type of crash. • Problems/complaints about individual locations are reviewed as needed. • All recorded crashes are kept in a database by the state DMV.

Table A.1 Continued.

11. If you can provide any relevant information (for example, studies, reports, or guidelines) pertaining to this survey, please respond below.
• In general city does not use these sorts of designs on new projects. One feature that they have not mentioned in survey is that they take more land, a feature that can be seen as detrimental to urban landscape and development in dense cities. It is also feature not popular with pedestrian safety advocates, who see them as old-style attempts to move traffic at their expense. • At present, we have ongoing research through the Texas Transportation Institute for the evaluation of edge-line and centerline rumble strips. • Our basic criteria for these include only installing them in areas with minimal pedestrian traffic. We've also found that they work best with lengthy acceleration and deceleration lanes. We currently have several on forced turn lanes and are considering converting another to a similar design. We've found these to work fairly well.



	Overhead crosswalk signs	Pedestrian crossing signs	Raised crosswalk	Speed hump/table	Distinguishable pavement	Rumble strips	Active warning devices	Pedestrian push button	Refuge islands	Flashing beacon	In ground LED's on crosswalk
I don't know	0	0	1	1	0	0	0	1	0	1	0
No	8	0	11	8	1	6	12	9	0	8	11
Yes	5	13	0	4	12	6	1	3	13	4	2

Figure A.1. Breakdown of Yes, No, and I don't know responses for the use of various pedestrian safety devices.