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Investigation of Exposure Based Pedestrian Accident Areas:

Crosswalks, Sidewalks, Local Streets and Major Arterials

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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16. Abstract

Previous FHWA research on pedestrian exposure identified four problem areas as promising candidates for accident reduction: intersections without marked pedestrian crosswalks, major arterial streets, local streets, and locations lacking sidewalks or pedestrian pathways.

~~This~~ report describes the results of a project undertaken to examine those four problem areas. The objectives of the project were to:

- Evaluate past research on pedestrian crosswalk markings and develop guidance for when and what type of crosswalk markings should be provided.
- Investigate traffic engineering improvements for major arterial streets to increase pedestrian safety;
- Investigate traffic engineering improvements for local streets to increase pedestrian safety.
- Examine existing guidance/warrants for the provision of pedestrian pathways and sidewalks and prepare revised guidance/warrants.

Appendix A contains abstracts and critical reviews of over 75 relevant literature citations. Appendix A is bound as a separate volume.

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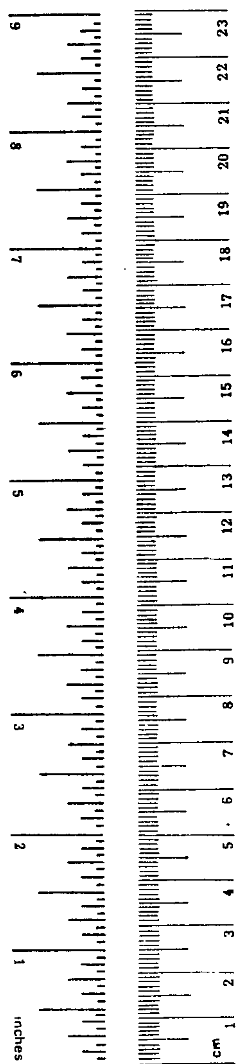
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

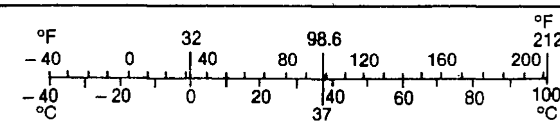
Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

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INTRODUCTION

PROJECT OBJECTIVES

Recent Federal Highway Administration (FHWA) research on pedestrian exposure (Tobey, Shunamen, & Knoblauch, 1983) successfully identified the relative hazard associated with many characteristics of pedestrian accidents by quantifying various roadway, intersection, pedestrian, and vehicle characteristics, and various precipitating and predisposing accident characteristics. Four problem areas were particularly promising candidates for accident reduction: intersections without marked pedestrian crosswalks, major arterial streets, local streets, and locations lacking sidewalks or pedestrian pathways.

This report describes the results of a project undertaken to examine those four problem areas. The objectives of the project were to:

- Evaluate past research on pedestrian crosswalk marking and develop guidance for when and what type of crosswalk marking should be provided.
- Investigate traffic engineering improvement for major arterial streets to increase pedestrian safety.
- Investigate traffic engineering improvement for local streets to increase pedestrian safety.
- Examine existing guidance/warrants for the provision of pedestrian pathways and sidewalks and prepare revised guidance/ warrants.

PROJECT ACTIVITIES

To meet the objectives, four tasks were undertaken, each corresponding to one of the four problem areas. A similar approach was used for each task. Each task started with an in-depth analysis of the exposure data collected during the previous project (Tobey, Shunamen, & Knoblauch, 1983) to further define the nature of the hazard associated with intersections with unmarked crosswalks, major arterials, local streets, and locations with no sidewalks or pathways. Each task also involved conducting a literature review and a state-of-the-practice review to determine current practices relevant to each of the problem areas.

A series of case studies of both new and existing traffic engineering improvements was conducted to determine if the treatments increased pedestrian safety in each of the problem areas.

A final activity was performed in two of the four problem areas. Revised guidance/warrants were developed for both crosswalk markings and pedestrian sidewalks and pathways. Draft sets of these warrants/guidelines were distributed to a number of practicing traffic engineers to obtain their comments and suggestions. Their responses were used to prepare final guidelines for the installation of crosswalk markings and sidewalks and pathways.

ORGANIZATION OF THIS REPORT

This report consists of four major sections, each addressing one of the four problem areas: crosswalk markings, major arterials, local streets, and sidewalks and pathways. The major topics in each of these sections include:

Chapter II - Investigation of Pedestrian Crosswalk Markings

- Analysis of pedestrian exposure data on crosswalk markings.
- State-of-the-practice review.
- Case studies of crosswalk marking projects.
- Laboratory evaluation of alternative crosswalk marking designs.
- Draft guidelines for marking pedestrian crosswalks.
- Practitioner reaction to draft guidelines.

Chapter III - Improvements to Major Arterial Streets

- Analysis of pedestrian exposure data on major arterials.
- State-of-the-practice review.

- Case studies of candidate improvements.

Chapter IV - Improvements to Local Streets

- Analysis of the pedestrian exposure data on local streets.
- State-of-the-practice review.
- Case study evaluation of local street improvements.

Chapter V - Revised Guidance for Pedestrian Pathways and Sidewalks

- Analysis of the pedestrian exposure data on sidewalks and pathways.
- State-of-the-practice review.
- Draft guidelines for sidewalk installation.
- Practitioner reaction to the guidelines.

The remainder of this chapter describes the pedestrian exposure data base that was analyzed in each of the four problem areas.

THE PEDESTRIAN EXPOSURE DATA BASE

One of the objectives of the study was to further analyze the pedestrian exposure data collected as pary of a previous FHWA research project, "Pedestrian Trip Making Characteristics and Exposure Measures" (Tobey, Shunamen, & Knoblauch, 1983). The objectives of the earlier project were to identify specific pedestrian trip making characteristics and behavior; develop pedestrian exposure measures; and determine the relative hazardousness of pedestrian behaviors, activities, and various situational factors. The exposure measures were compared to accident information to determine the relative hazardousness of various pedestrian characteristics and behaviors. It was from the results of this study that the four problem areas were selected for the current project: crosswalk markings, sidewalks, major arterials, and local streets.

In the pedestrian exposure study, a large-scale field study was conducted in five standard metropolitan statistical areas. Vehicular and pedestrian volumes and pedestrian activity were observed and recorded. In addition, pedestrians were coded by demographic characteristics and behavior. The sites at which the vehicle and pedestrian observations were made were described, measured, and photographed. The pedestrian exposure data were presented in terms of various pedestrian and site characteristics.

Hazard scores were developed to analyze the relationship between the occurrence of certain factors in the accident population and their occurrence in the population at risk. These hazard scores are the ratio created by dividing the percentage of occurrence of a characteristic in either the accident population or the exposure population by the percentage occurrence in the other population. To maintain an interval scale, the larger percentage is always divided by the smaller percentage. Thus, hazard scores always have an absolute value greater than or equal to 1.0. If the accident population has the larger percentage -- an indication that more hazard is associated with the characteristic -- the hazard score is presented as a positive number. If the exposure population had the larger percentage, the hazard score is presented as a negative number -- an indication that less hazard is associated with the characteristic.

Three types of hazard scores were examined: site hazard scores, pedestrian volume hazard scores, and PxV hazard scores. Site hazard scores are based on how frequently sites with various characteristics occur in the accident population relative to the general population of sites at risk. Pedestrian volume hazard scores are based on the percentage of the total national projection of crossing pedestrians found at each type of site. The PxV hazard scores are based on the exposure measure PxV -- the number of pedestrians (P) times the number of vehicles (V). The PxV hazard scores associated with a type of location are based on the percentage of the PxV exposure occurring at that type of location.

To understand how hazard scores can be used to determine the relative hazardousness of various factors, examine the data in the following chart.

VARIABLE	% OF NATIONAL PROJECTIONS OF:				HAZARD SCORE		
	ACCI-DENTS	SITES	PEDS	P x V	SITES less ±1 more	PEDS less ±1 more	P x V less ±1 more
ROADWAY FUNCTIONAL CLASSIFICATION							
MAJOR ARTERIAL HIGHWAY	17.0	2.6	5.0	8.1	6.5	3.4	2.1
COLLECTOR DISTRIBUTOR	30.8	14.5	38.2	61.2	2.1	-1.2	-2.0
LOCAL STREET	39.4	69.5	52.7	24.0	-1.8	-1.3	1.6
OTHER	12.9	13.4	4.1	6.7	-1.0	3.2	1.9

Major arterial highways account for 17.0 percent of the national projection of total pedestrian accidents. Yet, they account for only 2.6 percent of the national projection of sites. Thus, a site hazard score of 17.0 divided by 2.6 or +6.5 is computed. Major arterials are 6.5 times more overrepresented in accidents than would be expected based on the number of sites. Major arterials accounted for 5.0 percent of the total national projection of pedestrians observed. The pedestrian hazard score is computed by dividing 17.0 by 5.0. The pedestrian hazard score of +3.4 indicates that major arterials have 3.4 times more accidents than we would have expected based on the number of pedestrians observed. Finally, major arterials had 8.0 percent of the national projection of total PxV exposure (pedestrians observed times vehicles observed). By dividing 17.0 by 8.1, a PxV hazard score of 2.0 was computed. Major arterials have 2.1 times more accidents than they do PxV exposure.

On the other hand, collector-distributors, with a PxV hazard score of -2.0, are relatively safe. Apparently roadways where pedestrian-vehicle interactions are relatively frequent (collector-distributors) are safer than roadways where there are fewer pedestrians and more vehicles (major arterials) or roadways where there are fewer vehicles and more pedestrians (local streets).

The factors that were examined in the earlier pedestrian exposure study were classified in terms of the following roadway characteristics, intersection characteristics, and pedestrian/vehicle characteristics:

Roadway Characteristics

- Functional Classification
- Number of Lanes
- Length of Block
- Road Surface Material
- Road Surface Condition
- Shoulder Surface Material
- Median Type
- Roadway Center Markings
- Roadway Edge Markings
- Roadway Lane Markings
- Channelization
- Parking Restrictions
- Parking Meters
- Parking on Commercial Premises
- Pedestrian Accommodations
- Curbs
- Street Lighting
- Commercial Lighting

Intersection Characteristics

- Adjoining Land Use
- Intersection Type
- Lane Configuration
- Signalization
- Right Turn on Red
- Left Turning
- Signs

Pedestrian and Vehicle Characteristics

- Pedestrian Age
- Pedestrian Sex
- Pedestrian Accompaniment
- Pedestrian Mode
- Pedestrian Crossing Location
- Pedestrian Signal Response
- Vehicle Action
- Vehicle Type
- Accident Time of Day
- Accident Type

The exposure data base was examined in terms of the four areas of concern in this project. For crosswalk markings, each of the factors in the data base was analyzed in terms of its hazard score when there were no marked crosswalks and when all crosswalks were marked. From this analysis, we hoped to identify certain characteristics that describe where or under what conditions pedestrian safety was enhanced when crosswalks were marked. A similar approach was used to compare hazard scores or various kinds of locations with sidewalks and with no sidewalks. In addition, certain characteristics were identified that describe under what conditions marked crosswalks or sidewalks did not contribute to pedestrian safety. For major arterials and local streets, the data base was subdivided by functional classification and hazard scores were computed for each functional classification. From that analysis, we hoped to identify certain characteristics of major arterials on local streets as hazardous and other characteristics as safe.

In some cases, a characteristic was found to be neither hazardous nor safe, i.e., "neutral," in terms of affecting pedestrian safety. This neutrality was arbitrarily defined by hazard scores ranging from -1.3 to +1.3. Hazard scores in this range indicated that the difference between the two percentages was small enough not to be of major importance.

CHAPTER II
INVESTIGATION OF PEDESTRIAN CROSSWALK MARKINGS

INTRODUCTION

This chapter summarizes the activities involved in Task A, the investigation of pedestrian crosswalk markings. The principal objective of the task was to develop improved guidance/warrants for crosswalk markings. Six major activities were performed to achieve this goal:

- Analysis of pedestrian exposure data.
- State-of-the-practice review.
- Case studies of crosswalk marking projects.
- Laboratory evaluation of alternative crosswalk marking designs.
- Development of draft guidelines.
- Solicitation of practitioner reaction to draft guidelines.

An in-depth analysis of the exposure data collected in the previous FHWA research project, "Pedestrian Trip Making Characteristics and Exposure Measures," was conducted to identify those locations and/or situations where the installation of pedestrian crosswalks leads to an improvement in pedestrian safety and to determine when pedestrian crosswalks may result in increased hazard to pedestrians.

The state-of-the-practice review involved contacting local officials to determine the current state-of-the-practice in terms of installing pedestrian crosswalks. We used these contacts to determine when crosswalks are installed.

The case studies consisted of the before/after evaluation of pedestrian crosswalk markings at three locations:

- Belleview Road, Fairfax, Virginia.
- Eisenhower Avenue, Alexandria, Virginia.
- Ft. Lincoln, Washington, D.C.

The state-of-the-practice review revealed tremendous variety in the style and design of pedestrian crosswalk markings. Each jurisdiction seemed to believe that its marking system is the most visible and most effective. A laboratory study was conducted to test the conspicuity of a variety of pedestrian crosswalk marking patterns.

After conducting the exposure data analysis, the state-of-the-practice review, and several field studies, it was apparent that guidelines for the installation of crosswalks were needed. A set of draft guidelines was developed and distributed to a number of practicing traffic engineers to solicit their reactions. Their responses were considered in preparing the final guidelines for the installation of crosswalk markings.

ANALYSIS OF PEDESTRIAN EXPOSURE DATA ON CROSSWALK MARKINGS

The previous study on pedestrian exposure measures determined that sites with unmarked crosswalks have a PxV hazard score of +2.5. Locations with crosswalks marked on only one roadway were found to be neither particularly hazardous nor particularly safe. Locations with both crosswalks marked had a PxV hazard score of -2.5, indicating that they were relatively safe. This suggests a reasonable level of hazard reduction was associated with sites having all the crosswalks marked.

While the exposure data base defined crosswalk markings in three ways -- unmarked, marked on one roadway, and marked on both roadways -- only two types of crosswalk markings were analyzed. The data for crosswalks marked on one roadway were not analyzed since we do not know whether the accidents occurred on the leg with the marked or unmarked crosswalk. These locations represented only 8.1 percent of the sites and 12.0 percent of the accidents in the data base. When the data base was categorized by factors and crosswalk markings, the percentage in the Marked on One Roadway category was often too small. Therefore, the percentages in the tables in this section do not add up to 100 because those with crosswalks marked on one roadway were eliminated.

By examining each of the variables, we identified the characteristics of locations where marked crosswalks do not increase pedestrian safety and locations where unmarked crosswalks are safe. Based on this information, we determined characteristics of sites that would benefit from marking crosswalks and characteristics of sites for which some other pedestrian safety measure may be needed.

The data showed that for nearly all variables, sites with marked crosswalks were safer than unmarked crosswalks. These variables are discussed below.

Functional Classification

For collector-distributors and local streets, marked crosswalks had a safe PxV hazard score, whereas unmarked crosswalks had a hazardous PxV hazard score. Thus, marking crosswalks on collector-distributors and local streets increased pedestrian safety.

Functional Classification	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Major Arterials							
Unmarked	47.1	63.2	32.6	44.7	-1.3	+1.4	+1.0
Marked	37.2	26.0	57.8	50.1	+1.4	-1.6	-1.4
Collector-Distributor							
Unmarked	51.9	65.9	27.7	14.5	-1.3	+1.9	+3.6
Marked	36.8	17.0	64.2	80.8	+2.2	-1.7	-2.2
Local							
Unmarked	73.7	83.2	71.0	49.1	-1.1	+1.0	+1.5
Marked	16.3	10.4	16.5	39.0	+1.6	-1.0	-2.4

For major arterials, the PxV hazard score for unmarked crosswalks was +1.0, neither safe nor hazardous; the percentage of accidents and percentage of PxV exposure were equal. The PxV hazard score for marked crosswalks was -1.4, safe. Thus, in terms of the PxV exposure score, sites on major arterials that have marked crosswalks were safe but sites with no marked crosswalks were not necessarily hazardous. However, in terms of pedestrian exposure alone, unmarked crosswalks were hazardous and sites with marked crosswalks remained safe. Unmarked intersections on collector-distributors and local streets were more hazardous than marked intersections. The greatest differences were seen when PxV exposure was considered.

Number of Lanes

In terms of the PxV hazard score, marked crosswalks were safe and unmarked crosswalks were hazardous regardless of the number of lanes. The greatest hazard, however, was at unmarked intersections with more than two lanes.

Number of Lanes	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Two or less							
Unmarked	75.2	84.3	69.5	47.6	-1.1	+1.1	+1.6
Marked	14.1	8.4	13.5	21.1	+1.7	+1.0	-1.5
More than two lanes							
Unmarked	42.4	60.7	15.6	13.3	-1.4	+2.7	+3.2
Marked	43.9	26.1	80.8	84.1	+1.7	-1.8	-1.9

Channelization

In terms of the PxV exposure measure, marked crosswalks were safe and unmarked crosswalks were hazardous regardless of whether the roadway was channelized. Unmarked channelized intersections were particularly hazardous in terms of PxV exposure.

Channelization	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None							
Unmarked	68.5	82.8	60.4	38.0	-1.2	+1.1	+1.8
Marked	20.8	8.8	24.4	42.0	+2.4	-1.2	-2.0
Channelization							
Unmarked	34.7	64.2	12.7	5.4	-1.8	+2.7	+6.4
Marked	48.7	30.6	86.8	94.0	+1.6	-1.8	-1.9

Parking Restrictions

There are five categories of parking restrictions in the exposure data base: permitted both sides, prohibited one side, prohibited both sides, roadway width restricts to one side, and roadway width restricts both sides. Further, restrictions vary by time of day. Insufficient data exist to analyze the last three types of parking restrictions by crosswalk markings. Also, the second and third categories were combined to provide a better sample size.

For the remaining two categories of parking restrictions, marked crosswalks were safe while unmarked crosswalks were hazardous in terms of the PxV exposure measure.

Parking Restrictions	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Permit Both Sides							
Unmarked	67.2	76.7	45.6	17.3	-1.1	+1.5	+3.9
Marked	19.5	13.2	39.2	73.0	+1.5	-2.0	-3.7
Prohibit One or Both Sides							
Unmarked	50.2	76.5	39.8	15.2	-1.5	+1.3	+3.3
Marked	39.2	17.3	50.4	15.2	+2.3	-1.3	-1.8

Pedestrian Accommodations

For sites with no sidewalks, the PxV hazard score for unmarked crosswalks was hazardous and the PxV hazard score for marked crosswalks was safe. As might be expected, sites with no sidewalks are less likely to have marked crosswalks. At places with no sidewalks, 89.2 percent were unmarked and only 5.1 percent had all crosswalks marked. (The remaining 5.7 percent had marked crosswalks on only one road.) However, the PxV hazard scores showed that in terms of pedestrian and vehicle volumes, marked crosswalks were considerably safer. However, this hazard score for marked crosswalks/no sidewalks was based on only 1.7 percent of all accidents and only 1.8 percent of all sites in the exposure data base.

For sites with sidewalks on both sides, marked crosswalks had a safe PxV hazard score while unmarked crosswalks had a hazardous PxV hazard score.

Pedestrian Accommodations	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
No Sidewalks							
Unmarked	85.6	89.2	50.4	11.4	-1.0	+1.7	+7.5
Marked	9.2	5.1	19.4	84.8	+1.8	-2.1	-9.2
Sidewalks - Both Sides							
Unmarked	55.2	77.3	51.1	26.8	-1.4	+1.1	+2.1
Marked	31.6	12.1	40.2	66.1	+2.6	-1.3	-2.1

Street Lighting

Only sites with regularly spaced street lighting were examined in terms of crosswalks because less than 1 percent of the sites in the data base had marked crosswalks and no street lighting or street lighting not regularly spaced.

However, for sites with regularly spaced street lighting, marked crosswalks were safe and unmarked crosswalks were hazardous in terms of the PxV hazard score.

Street Lighting	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Regularly Spaced							
Unmarked	57.6	76.9	49.2	22.4	-1.3	+1.2	+2.6
Marked	30.3	14.7	39.7	66.2	+2.1	-1.3	-2.2

Commercial Lighting

For sites with commercial lighting, either continuous or not continuous street lighting, marked crosswalks had a safe PxV hazard score and unmarked crosswalks had a hazardous PxV hazard score.

However, for sites with no commercial lighting, marked crosswalks were safe while unmarked crosswalks were not particularly safe or hazardous.

Commercial Lighting	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None							
Unmarked	73.2	84.0	71.1	56.6	-1.2	+1.0	+1.3
Marked	15.0	8.3	16.1	29.9	+1.8	-1.1	-2.0
Continuous							
Unmarked	41.7	56.4	8.0	6.1	-1.4	+5.2	+6.8
Marked	48.8	27.7	81.3	79.1	+1.8	-1.7	-1.6
Not Continuous							
Unmarked	44.8	62.4	31.3	12.5	-1.4	+1.4	+3.6
Marked	40.6	28.5	55.0	82.1	+1.4	-1.4	-2.0

Adjoining Land Use

In residential, commercial, and mixed residential and commercial areas, locations with unmarked crosswalks were hazardous. Marked crosswalk intersections were found to be relatively safe in commercial and residential areas. Since only 1.1 percent of all the sites in the data base were in mixed residential areas with marked crosswalks, the hazard scores are not presented.

Land Use	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
100% Residential							
Unmarked	79.2	85.1	75.1	51.1	-1.1	+1.0	+1.6
Marked	9.5	9.5	15.5	32.4	+1.0	-1.6	-3.4
Commercial							
Unmarked	45.8	68.1	34.3	17.7	-1.5	+1.4	+2.6
Marked	43.6	25.9	60.9	79.6	+1.7	-1.4	-1.8

Intersection Type

The analysis of the hazard scores for several of these categories was restricted due to the distribution of accidents and/or sites in the data base. Marked 4-leg intersections had a safe PxV hazard score while unmarked 4-leg intersections were found to be hazardous.

Intersection Type	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
4-Leg							
Unmarked	49.9	70.0	49.2	23.3	-1.4	+1.0	+2.1
Marked	40.5	24.1	45.5	72.6	+1.7	-1.1	-1.8

Lane Configuration

Marked crosswalks at 2x2 and 2x4 lane intersections were safer than unmarked crosswalks at those locations. Generally, crosswalks had been marked at those 4x4 intersections that carry the majority of the PxV exposure. For these sites, marked crosswalks were not particularly safe nor particularly hazardous. While 96 percent of the exposure was at these sites, they had only 72 percent of the accidents, with a hazard score of only -1.3.

Lane Configuration	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
2 x 2							
Unmarked	78.7	84.9	70.5	49.6	-1.1	+1.1	+1.6
Marked	10.3	8.1	13.4	20.1	+1.3	-1.3	-2.0
2 x 4							
Unmarked	57.5	72.7	53.5	47.0	-1.3	+1.1	+1.2
Marked	27.8	12.4	30.6	38.1	+2.2	-1.1	-1.4
4 x 4							
Unmarked	18.9	42.9	2.7	2.5	N/A	N/A	N/A
Marked	72.1	48.0	96.1	96.5	+1.5	-1.3	-1.3

Signalization

Unsignalized intersections with marked crosswalks were safe and unsignalized intersections with unmarked crosswalks were hazardous in terms of the PxV exposure measure. As expected, the majority of unsignalized intersections had no marked crosswalks.

The majority of intersections with red, green, amber (RGA) signals had marked crosswalks which were safe, while unmarked crosswalks were hazardous.

The majority of intersections with RGA and pedestrian signals also had marked crosswalks. For these intersections, unmarked crosswalks were hazardous and marked crosswalks were safe, but the hazard score was only -1.3 (67.2 percent of accidents occurred at sites with 88.1 percent of the exposure).

Signalization	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None							
Unmarked	84.2	85.4	75.4	61.7	-1.0	+1.1	+1.4
Marked	4.2	6.5	7.6	8.5	-1.6	-1.8	-2.0
Red, Green, Amber							
Unmarked	25.0	32.9	10.1	6.6	-1.3	+2.5	+3.8
Marked	62.8	64.8	87.1	91.2	-1.0	-1.4	-1.4
RGA & Ped Signal							
Unmarked	20.1	16.4	15.4	7.6	+1.2	+1.3	+2.6
Marked	67.2	70.0	78.7	88.1	-1.0	-1.2	-1.3

Summary

As stated earlier, in terms of the PxV exposure measure, marked crosswalks were safe and unmarked crosswalks were hazardous for the majority of roadway characteristics. The exceptions were:

- At major arterials, where unmarked crosswalks were neither hazardous nor safe, but marked crosswalks were safe.
- At locations with no commercial lighting, where unmarked crosswalks were neither hazardous nor safe, but marked crosswalks were safe.

Marking crosswalks did not make a difference in terms of the P exposure measure for many roadway characteristics. The following characteristics had neutral P hazard scores for both marked and unmarked crosswalks; however, the PxV hazard scores for marked crosswalks for these characteristics were safe.

- Roadway Functional - Local streets.
- Number of Lanes - Two or less.
- Channelization - None.
- Parking Restrictions - Prohibited.
- Sidewalks - Both sides.
- Street Lighting - Regularly spaced.
- Commercial Lighting - None.

The majority of intersection characteristics also had hazardous PxV hazard scores for unmarked crosswalks and safe PxV hazard scores for marked crosswalks. The exceptions were:

- At sites with a 2x4 lane configuration, where unmarked crosswalks were neither safe nor hazardous while marked crosswalks were safe.
- At sites with RGA signals with pedestrian signals, where unmarkedcrosswalks were hazardous, but marked crosswalks were neither safe nor hazardous.

CASE STUDY: BELLEVIEW BOULEVARD CROSSWALK STUDY

Belleview Boulevard is a major east-west collector-distributor passing through residential and commercial areas in southern Fairfax County, Virginia. The segment of interest was a section approximately 1/2-mile long that connects the George Washington Parkway with Ft. Hunt Road, both of which are major north-south arterials. Belleview Boulevard carries moderate vehicle volumes and has relatively low pedestrian volumes. Previously, there was only one intersection with a marked pedestrian crosswalk. The proposed crosswalk marking project provided an excellent opportunity to evaluate the effect of crosswalk markings in a before/after with control group design.

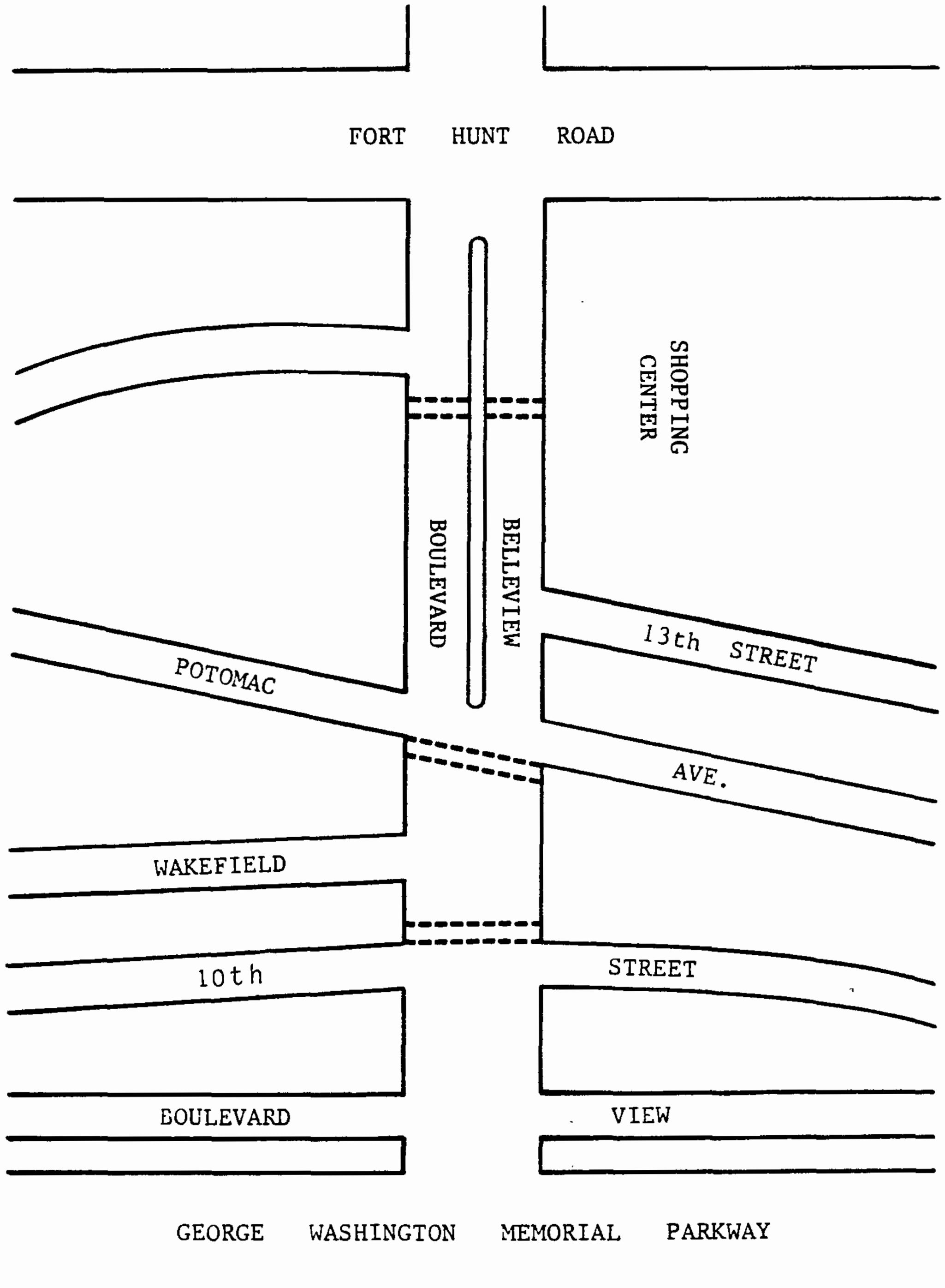
As shown in figure 1, of the four intersections along the segment, only one had a marked crosswalk. The marking project called for two new crosswalks to be installed and the one existing crosswalk to remain in place. The fourth intersection would receive no treatment. The following summarizes the experimental plan:

Location	Site No.	Before	After
Belleview at:			
Shopping Center	I	Marked	Marked
Potomac	II	Unmarked	Marked
Tenth	III	Unmarked	Marked
Wakefield	IV	Unmarked	Unmarked

Thus, the following design was completed:

	Before	After
Marked	I	I, II, III
Unmarked	II, III, IV	IV

The purpose of the data collection was to determine the effect of crosswalk markings on driver and pedestrian behavior. The following behaviors were observed:



NOTE: Dashed lines indicate marked crosswalks.

Figure 1. Belleview Boulevard crosswalk study site.

- Vehicle Speed, no pedestrian present.
- Vehicle Speed, pedestrian on roadway.
- Vehicle Speed, pedestrian on roadside.
- Pedestrian Crossing Location
  - Totally in crosswalk.
  - Partially in crosswalk.
  - Within 50 feet of crosswalk.
  - More than 50 feet from crosswalk.
- Pedestrian Looking Behavior
  - Prior to entering roadway.
  - During crossing.

A trained data collector observed pedestrian activity and measured vehicle speeds with a hand-held Decatur radar gun from within a vehicle legally parked near the crosswalk. Each site was observed for 15 minutes and the observer moved to the next site. Thus, each of the locations was observed twice during a 2-hour segment.

Data were collected for a total of 20 hours before the crosswalks were installed and for a similar period several months after they were installed. The after data were collected several months after the crosswalks were installed because the project was not concerned with short-term or acclimation effects. Although vehicle speed data were collected for free-flow vehicles whenever a pedestrian was present, there were few such cases to permit analysis. All of the vehicle speed data presented are for free-flow speed with no pedestrian present.

The following hypotheses were tested:

(1) Driver behavior is not affected by marked pedestrian crosswalks.

(2) Pedestrians are not as careful in a marked crosswalk as in an unmarked crosswalk.

Results

The results shown below suggest that there was very little difference in the mean travel speed in the before and after conditions at all four locations.

	Before	After	Change
Shopping Area	29.7 mi/h (marked)	28.7 mi/h (marked)	-1.0 mi/h
Potomac	28.5 mi/h (unmarked)	28.5 mi/h (marked)	None
Tenth	28.2 mi/h (unmarked)	29.2 mi/h (marked)	+1.0 mi/h
Wakefield	29.0 mi/h (unmarked)	29.5 mi/h (unmarked)	+0.5 mi/h

This, coupled with the fact that there was no strong directionality of the small changes noted (i.e., speeds decreased at the marked control site and increased at the unmarked control), leads one to believe that the presence or absence of a crosswalk marking had little effect on driver behavior. There was also little variation in the travel speeds even when examined by time of day and direction (eastbound/westbound).

A 4x2 (site x condition) analysis of variance with mean travel speed as the dependent variable indicated there was a significant interaction between site and condition ($F[3,2379]=4.26$, $p<0.005$). Mean speed decreased at the marked control site and increased at one of the experimental sites. Since there were no consistent effects due to crosswalk markings, the data suggest that the presence or absence of a crosswalk marking had little effect on driver behavior.

The analysis of the pedestrian behavioral data suggests that the presence or absence of a crosswalk also had little effect on the pedestrians. As shown below, there appeared to be a change in the crossing location at the shopping center in the before (46.5 percent in crosswalk) and after (59.3 percent in crosswalk) condition. Since this was a control location, such a change was not expected from merely repainting an existing crosswalk. However, a 4x2 chi-square comparing the crossing location of pedestrians before and after at the shopping center site revealed no significant difference.

	Site/Condition, %			
	Control Site		Experimental Sites	
	Shopping Center		Potomac	Tenth
Crossing Location	Before	After	After	After
Totally in Crosswalk	46.5	59.3	22.6	29.2
Partially in Crosswalk	4.7	6.8	9.7	8.3
Within 50 ft of Crosswalk	25.6	16.9	51.6	41.7
Over 50 ft from Crosswalk	23.3	16.9	16.1	20.8

The table below shows that looking behavior apparently increased at both the marked control site (shopping center) and the unmarked control site (Wakefield). One of the experimental sites (Potomac) showed a slight increase in looking behavior prior to crossing but an overall decrease in looking behavior both before and during the crossing. The second experimental site (Tenth) showed negligible changes in pedestrian looking behavior. When these looking behavior data were analyzed using a 2x2 chi-square comparing looking behavior before and after at each site, no significant differences were found.

	Site/Condition, %								
Looking	Shopping Center		Potomac		Tenth		Wakefield		
Behavior	Before	After	Before	After	Before	After	Before	After	Total
Prior to Crossing	60.0	50.8	26.3	35.5	26.7	29.2	33.3	31.3	40.2
Prior to and During Crossing	40.0	49.2	73.7	64.5	73.3	70.8	55.6	68.8	59.4

The analysis of the behavioral data indicates that there were little or no changes in pedestrian behavior resulting from the installation of the pedestrian crosswalk markings.

CASE STUDY: EISENHOWER AVENUE CROSSWALK STUDY

This study was performed to see if the presence or absence of crosswalks had any effect on pedestrian or motorist behavior. The study used several different measures of effectiveness in before and after situations to assess differences in pedestrian and motorist behavior.

Eisenhower Avenue is a two-way, four-lane divided arterial street in Alexandria, Virginia. Built to access the Washington Metropolitan Area Transit (Metro) subway station of the same name, Eisenhower Avenue does not operate as an arterial street. The average daily traffic volumes and the hourly distribution of those volumes do not fit the pattern of an arterial street. Except for parking lot entrances, there are few intermediate access points and no traffic signals. It is essentially a road designed to access the transit station and provide the capacity for the peak hour kiss-and-ride operations. One major office building in the area benefits from the location of the road, but the majority of the traffic appears in the morning and evening peaks.

The pedestrian traffic in the area consists of office building employees who are crossing Eisenhower Avenue to get to and from the building to the Metro station or the auxiliary parking lot for the building. The automobile traffic is composed of the kiss-and-ride subway patrons and building employees who commute by auto and park at the site. A sketch of the site is shown in figure 2.

Measurements were taken of several different parameters before there was a crosswalk and after it was installed. Pedestrians were observed going to and from the Metro station and the office building. Observations included an estimate of age, sex, looking behavior (whether there was head movement), length of time in the roadway, direction of travel, time of day, and location of the pedestrian in or out of the crosswalk area.

The length of time in the roadway was recorded by stopwatch. The watch was started as the pedestrian stepped off the curb and stopped as the pedestrian stepped up and out of the roadway. If the pedestrian hesitated, for any reason, during the crossing, the total hesitation time was noted also. Looking

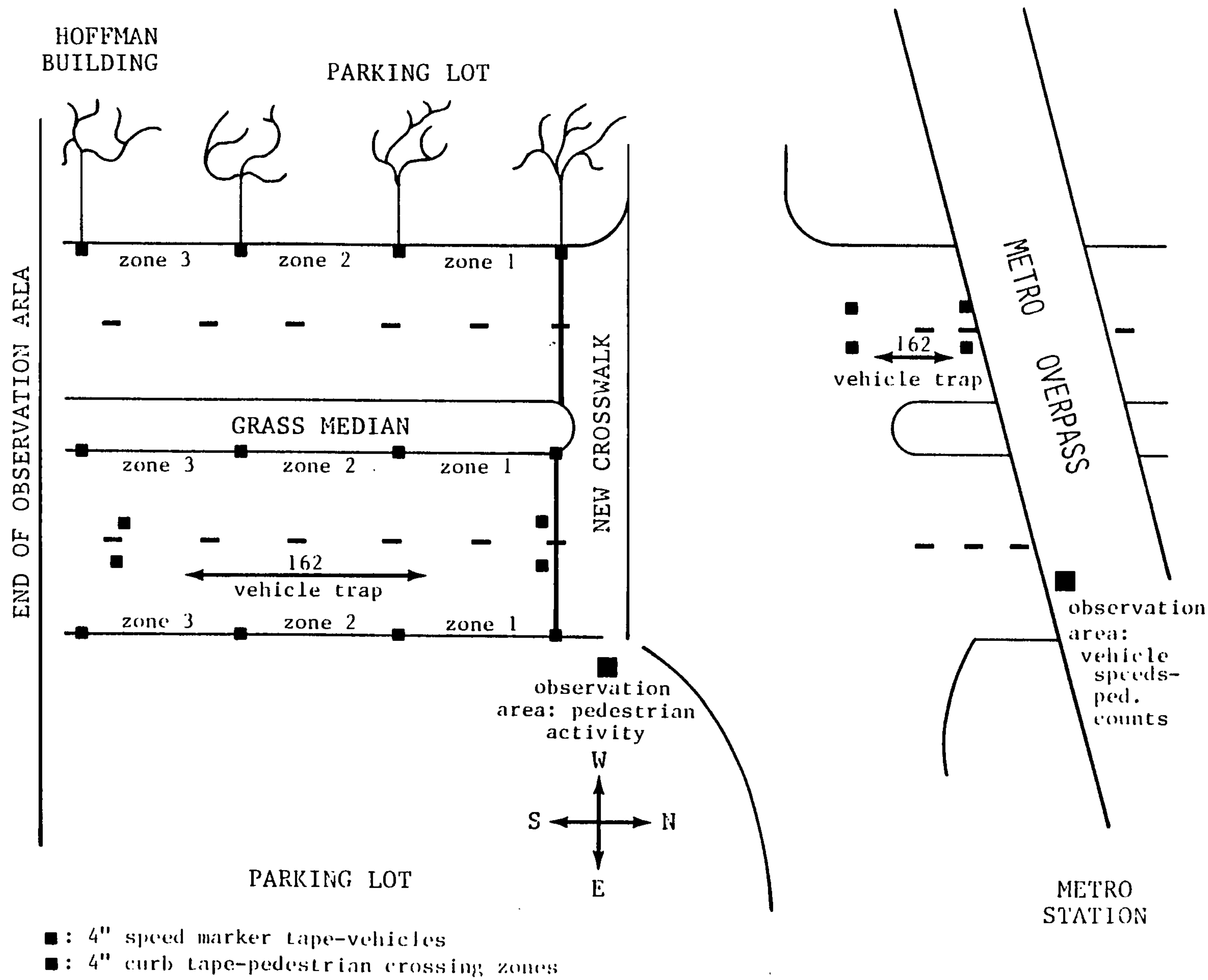


Figure 2. Eisenhower Avenue crosswalk study site.

behavior was recorded as the pedestrian approached the crossing, during the first half of the crossing, approaching the second half of the crossing, and during the second half of the crossing.

To systematize the pedestrian crossing location procedure, zones were marked with small pieces of white tape on the curbs of both sides of the street and median so the observer could clearly see where the pedestrian entered and exited the roadway relative to the crossing. Crossing location was recorded by zone, as was looking behavior. A manual count of the pedestrian volumes by direction was also made.

Vehicle speeds were measured for instances when there were no pedestrians in the roadway and when pedestrians were crossing. Vehicle traps of 162 feet were measured and marked with small pieces of white tape on northbound and southbound Eisenhower Avenue. A stopwatch was used to measure the speed of cars, trucks, and buses. The type of vehicle was recorded along with direction of travel and pedestrian activity within the observation zone.

Results

A t-test showed there was no change in vehicle approach speeds from before to after the crosswalk was installed. The mean travel speed for each condition was 29.7 mi/h. Although brake light applications, pedestrian-induced hesitations, pedestrian-vehicle conflicts, and yielding to pedestrians were observed, they occurred so infrequently during both the before and after periods that no tendencies were apparent and no statistical analyses were appropriate.

In the before condition when there was no crosswalk, the pedestrians were observed to see if they took a perpendicular path across the road similar to the path they would follow if a crosswalk had been there. As shown in the following chart, there was some evidence that after the crosswalk was in place the number of people crossing in the crosswalk area increased. The location of a pedestrian during a crossing was noted at four points: before crossing, during the first half of the crossing, at the median, and during the second half of the crossing. Chi-squares showed that the percentage of pedestrians staying in the crossing, and thereby minimizing their time in the roadway, significantly increased after the crosswalk was marked.

Location	% of Pedestrians in Crosswalk Before (N=472)	After (N=611)	Percent Change
Before Crossing	47	57	+10
During First Half	35	49	+14
At Median	22	48	+26
During Second Half	29	45	+16

The looking behavior of the pedestrians was also observed at each point where the crossing location was observed: before crossing, during the first half of the crossing, at the median, and during the second half of the crossing. Pedestrian looking behavior changes found after the crosswalk was installed are shown in the table below. The only significant difference in looking behavior was found during the first half of the crossing. Although all of the pedestrians looked before entering the roadway both before and after the crosswalk was installed, significantly fewer pedestrians looked during the first half of the crossing after the crosswalk was installed.

Location	% of Pedestrians Looking Before (N=472)	After (N=611)	Percent Change
Before Crossing	100	100	0
During First Half	69	42	-27
At Median	88	85	- 3
During Second Half	38	42	+ 4

In conclusion, the Eisenhower Avenue crosswalk installation produced no observable effect on motorist behavior. Whether there was an increase in awareness or a change in driver expectancy produced by the crosswalk is not known. On the other hand, the crosswalk did change two pedestrian behaviors. First, pedestrians tended to stay in the crosswalk (i.e., go straight across, not diagonally) and thus minimized their exposure time. Second, although there was no change in the number of pedestrians looking before entering the roadway, fewer pedestrians continued to look during the first half of the crossing. There was no change in pedestrian looking behavior during the second half of the crossing.

CASE STUDY: FT. LINCOLN CROSSWALK STUDY

Ft. Lincoln is an area of urban redevelopment in Washington, D.C. Built on the site of an old military post, Ft. Lincoln is a planned community of townhomes nested in a curvilinear street system.

Ft. Lincoln Drive is a major collector street running through the development. For most of its length, Ft. Lincoln Drive is a four-lane divided road; however, when it passes the local grammar school it narrows to a two-lane undivided section. In this two-lane section of Ft. Lincoln Drive is a midblock crosswalk linking the school with nearby housing areas.

In an effort to add more visibility to this midblock pedestrian/school crossing, the District of Columbia Government decided to change the crosswalk configuration. The initial pattern was two parallel lines spaced 8 feet apart. The new pattern is a hatched diagonal configuration. This change in the crosswalk configuration presented an interesting opportunity to see if different crosswalk patterns affected driver or pedestrian behavior.

Data were collected on vehicle speeds (using radar) and pedestrian crossing and looking behavior.

Results

The results showed little difference in the mean vehicle speeds between the two different marking types at the Ft. Lincoln site. For the parallel line crossing, the mean travel speed was 28.4 mi/h. For the diagonal line crossing, the mean travel speed was 29.4 mi/h. The type of crossing had no significant effect on motorist behavior.

Analysis of the pedestrian behavioral data showed some differences in crossing location between the two types of crosswalk markings.

As shown in the following chart, when the parallel lines were in place, 47.2 percent of the pedestrians crossed totally in the crosswalk. After the diagonal configuration was installed, this increased to 59.2 percent. Since the number of pedestrians who crossed partially in the crosswalk (late entry or early departure) decreased from 9.0 percent to 3.3 percent, it appears that the diagonal crosswalk is somewhat more effective in attracting pedestrians and at retaining them during the entire crossing.

% of Pedestrians Who Crossed	Type of Crossing: Parallel Lines	Type of Crossing: Diagonal Lines
Totally in Crosswalk	47.2	59.2
Partially in Crosswalk	9.0	3.3
Within 50 ft of Crosswalk	18.4	19.2
Over 50 ft from Crosswalk	25.4	18.3
Total	100.0	100.0

There was also a change in the looking behavior between the parallel line marking and the diagonal marking. The majority of the shift took place between the "did not look" category and the "looked prior to and during" category. The table below shows that 39.5 percent of the pedestrians observed did not look when the parallel line marking was in place and only 4.7 percent looked prior to and during crossing. When the diagonal marking was in place, only 9.2 percent did not look, while the number of pedestrians who looked prior to and during crossing rose to 41.7 percent.

% of Pedestrians Who:	Type of Crossing: Parallel Lines	Type of Crossing: Diagonal Lines
Did Not Look	39.5	9.2
Looked Prior to Entering	49.8	42.5
Looked During Crossing	6.0	6.7
Looked Prior to and During	4.7	41.6
Total	100.0	100.0

At the Ft. Lincoln test site, the diagonal configuration was somewhat more effective than the parallel lines at inducing pedestrians to use the crosswalk and also resulted in an increase in the number of pedestrians who looked for oncoming traffic prior to and during crossing.

LABORATORY EVALUATION OF ALTERNATIVE CROSSWALK MARKING DESIGNS

Introduction

One element of this task was an experiment to determine if there was any difference in visibility between different crosswalk configurations from a driver's point of view. Three basic formats were tested: the edgelines, the diagonal or hatched, and the ladder. Variations of these basic formats using different combinations of paint width and spacing represent many of the different patterns that are used today.

While it is not clear how the many patterns evolved, several factors determine the optimal crosswalk configuration: ease/cost of initial placement, ease/cost of maintenance, conspicuity/visibility/comprehension of the marking by motorists, and comprehension of the marking by pedestrians. The first two factors go hand in hand. The more labor-intensive a marking is to put down and the greater the amount of materials (paint, glass bead, thermoplastic) the configuration requires is a direct measure of how costly the markings are going to be to install and maintain. Thus, simple patterns that use a minimum amount of materials cost less. In terms of conspicuity, visibility, and comprehension of the markings by motorists, the design of the configuration must catch the motorists' attention and be recognized as a crosswalk (seen and understood).

This experiment was a test of different crosswalk marking configurations to see if there was a difference in the "ability" of the different markings to be recognized as crosswalks as opposed to other transverse pavement markings and no markings at all. The marking patterns used were representative of the three basic configuration types and current practice. Some experimental crosswalk pattern designs were also generated following strategies related to ease/cost of installation and maintenance. The purpose of the experimental evaluation was to determine which crosswalk marking configuration was most readily detected by an approaching motorist.

Preparation of Stimuli

The test stimuli were 35mm slides of the different marking configurations placed in an actual field location. Full-scale pavement marking patterns were individually installed at the same location on a suburban residential street. After each pattern was in place, 35mm slide pictures were taken at distances of 50, 100, 200, 300, 400, 500, and 600 feet. The camera was positioned to simulate driver eye height and lateral position. The patterns used are shown in figure 3.

Photographs of two of the test patterns are shown in figure 4. These photographs were taken at a distance of 50 feet. Two other test patterns, the transverse word markings STOP and ONLY, were used as false targets. Slides taken of the test site when no markings were in place were also used as false target stimuli.

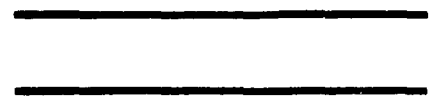
An attempt was made to have the laboratory conditions replicate the total visual input a driver would have in the field. The visual angle subtended to the eye by the width of the pattern in the field was calculated. This visual angle value was then used to determine the distance from the screen that a test subject should sit so that the field distances (i.e., 100, 200, etc., feet) would be simulated in the laboratory conditions.

In preparing the test stimuli, the experimenters previewed all of the slides. The slides taken at 100 feet were perceived as too easy to be misidentified. The markings in the slides at 600 feet were almost indiscernible. Therefore, these slides were eliminated from the test. A brief pilot test conducted on the rest of the slides revealed that the slides taken at 200 feet were never misidentified, so they too were eliminated from further testing.

The test slides were placed in random order for every pilot test and laboratory test in this study.

<u>Test Subjects</u>

The 59 test subjects were members of a church group. All were licensed drivers. While no strict limits were placed on age and sex, an attempt was made to test a representative sample of men and women of all ages. Twenty-nine (29) of the subjects were male and 30 were female. Eleven (11) were under 30 years old, 18 were 30 to 50, and 30 were over 50.

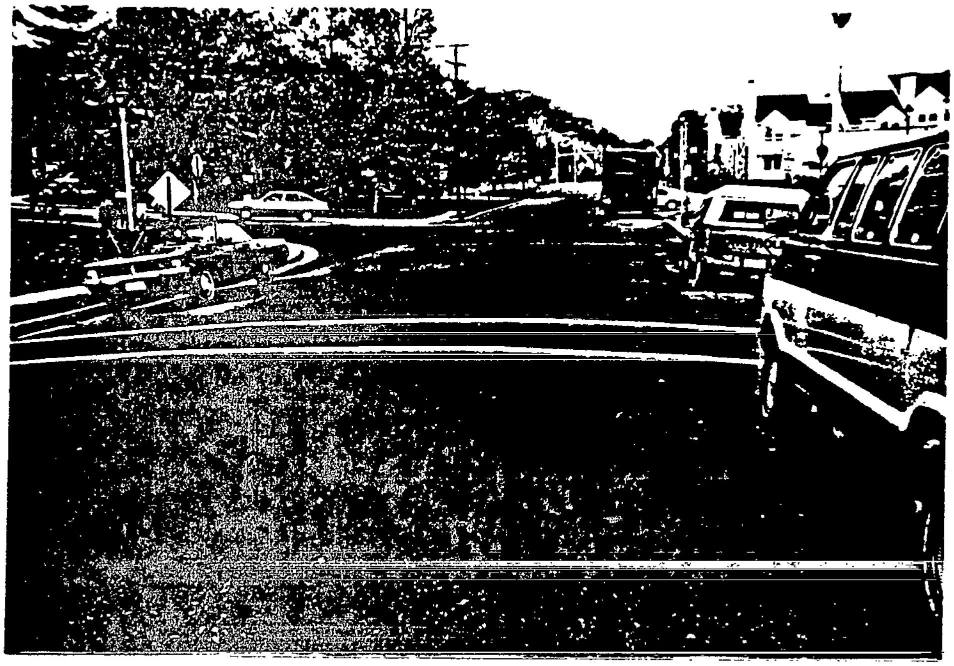
TEST PATTERN NUMBER	DESCRIPTION	
1	6-INCH WIDE EDGELINES	
2	12-INCH WIDE EDGELINES	
3	24-INCH WIDE EDGELINES	
4	12-INCH DIAGONAL STRIPE WITH 12-INCH SPACE	
5	12-INCH DIAGONAL STRIPE WITH 24-INCH SPACE	
6	12-INCH DIAGONAL STRIPE WITH 48-INCH SPACE	
7	12-INCH DIAGONAL STRIPE WITH 48-INCH SPACE WITH 8-INCH EDGELINES	
8	24-INCH DIAGONAL STRIPE WITH 24-INCH SPACE	
9	24-INCH DIAGONAL STRIPE WITH 48-INCH SPACE	

NOTE: FIGURE IS NOT TO SCALE;
BUT APPROXIMATE PROPORTIONS

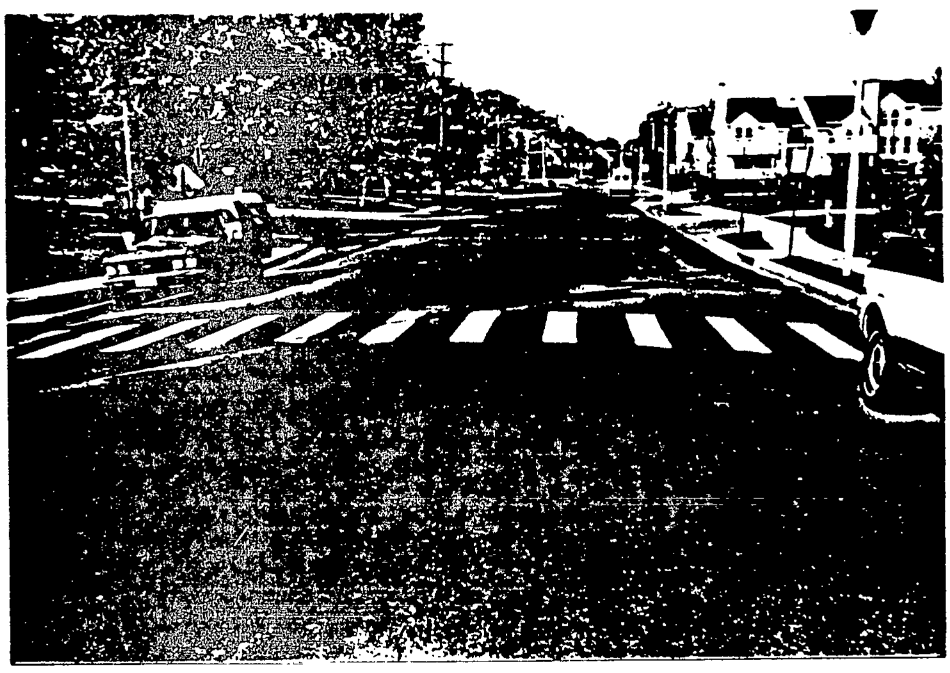
Figure 3. Crosswalk marking types.

TEST PATTERN NUMBER	DESCRIPTION	
10	12-INCH LADDER STRIPE WITH 12-INCH SPACE	
11	12-INCH LADDER STRIPE WITH 24-INCH SPACE	
12	12-INCH LADDER STRIPE WITH 48-INCH SPACE	
13	24-INCH LADDER STRIPE WITH 24-INCH SPACE	
14	24 x 12-INCH BOX WITH 24-INCH SPACED EDGELINES	
15	24 x 12-INCH BOX WITH 36-INCH SPACED EDGELINES	
16	24 x 12-INCH BOX WITH 48-INCH SPACED EDGELINES	
17	TRANSVERSE WORD MARKING STOP	**STOP**
18	TRANSVERSE WORD MARKING ONLY	**ONLY**

Figure 3. Crosswalk marking types (cont.).



Test pattern #1 - 6-inch wide edgelines.



Test pattern #11 - 12-inch wide ladder stripe with 24-inch spacing.

Figure 4. Typical crosswalk configuration test patterns.

Procedure

Before the experiment began, each subject was given a far vision binocular acuity test. After the test, the subjects were seated in chairs that were placed at a preset distance from the screen to simulate the field distances using the visual angle theory previously discussed. The subjects were tested in small groups. Each group was given a brief description of what the test was about and a set of instructions to fill out the response forms. They were told that slides in the test group might show lettering or even nothing rather than a crosswalk. They were asked to indicate on the answer sheet (figure 5), to the best of their ability, what they could see: nothing, something (not sure if it was a crosswalk or lettering, but sure it was not nothing), lettering or a crosswalk. The slide projector was preset to show a slide every 8 seconds. After 10 slides were shown, a blank slide was included to allow the subjects to turn the page of the test booklet.

Results

The vision test showed that only three of the test subjects had vision worse than a Snellen equivalent of 20/40. The subjects that tested for poorer vision did no better or worse than the rest of the test group, and, therefore, their results were included in the aggregate.

The results were analyzed using the number of correct responses (range 0 to 3) to a pattern by each subject (e.g., the number would be 3 if the 300-, 400-, and 500-foot slides were all identified correctly, and the number would be 2 for correctly identifying the 300- and 400-foot, or 300- and 500-foot slides, etc.) and calculating the mean number of correct responses for each pattern. One class of pattern emerged as the consistent best. That group was the ladder crossings. Within that group there was little difference between patterns 10, 11, and 13 (2.8, 2.7, and 2.8, respectively). Test pattern 12 tested well (2.2), but not quite as well as the others. Test pattern 15 scored well also (2.4), but the other "dashed" patterns did not do very well, which casts some doubt about the visibility of this type of pattern.

WHAT MARKINGS CAN YOU SEE ON THE ROAD AHEAD?

Slide #	Nothing	Something	Lettering	Crosswalk
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Figure 5. Subject response sheet.

Conclusions

It seems that the most effective pattern for marking crosswalks from a driver visibility point of view is a ladder type of marking. This follows sensory and perceptual theory in that the solid white bar seen by the eye in the parallel and diagonal type of crosswalk markings (the front of one diagonal line overlaps with the rear of the next diagonal line to create the solid white bar effect) is analogous to a less detectable low contrast grating and the ladder marking is similar to a more detectable high contrast grating (Kaufmann, 1979).

As mentioned earlier, the relative cost of each design alternative is important as well. The amount of paint needed for each design configuration to stripe a crosswalk across a 40-foot roadway is shown below. Of the three most visible patterns (numbers 10, 11, and 13), test pattern 11 uses the least amount of materials.

Test Pattern	Area of Marking (sq. ft.)
1	48
2	96
3	192
4	189
5	127
6	77
7	127
8	205
9	137
10	192
11	128
12	80
13	192
14	48
15	40
16	32

Given the laboratory test performance, the cost considerations, and the good detectability for pedestrians, a 12-inch ladder stripe and 24-inch space crosswalk marking configuration is recommended for use when possible.

GUIDELINES FOR THE INSTALLATION OF CROSSWALK MARKINGS

Introduction

The Manual on Uniform Traffic Control Devices (MUTCD) states the primary purposes of crosswalk markings (Section 3B-15):

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

It should be noted that a crosswalk legally exists across each leg of an intersection, even though it may not be marked.

The MUTCD provides only general guidelines regarding the application of crosswalk markings:

> "Crosswalks should be marked at all intersections where there is substantial conflict between vehicle and pedestrian movements. Marked crosswalks should also be provided at other appropriate points of pedestrian concentration, such as at loading islands, midblock pedestrian crossings, or where pedestrians could not otherwise recognize the proper place to cross."

The Manual goes on to discuss precautions against using crosswalk markings indiscriminately.

> "Crosswalk markings should not be used indiscriminately. An engineering study should be required before they are installed at locations away from traffic signals or STOP signs."

Background

Although there has never been a national policy on more specific guidelines for crosswalk installation, some States and cities have developed their own. In many localities crosswalks are marked in response to citizen or political requests and/or pressure. The public often places great confidence in crosswalk markings as a safety device. However, there is substantial controversy over the actual effectiveness of crosswalk markings and increasing concern that crosswalk markings are more of a detriment than a benefit to pedestrian safety. A 1970 study in San Diego (Herms, 1972) compared accident rates at marked versus unmarked crosswalks.

The accident rates of crosswalks at 400 unsignalized intersections that had one painted crosswalk and one unpainted crosswalk, both crossing the same main thoroughfare, were compared. Herms found that the painted crosswalks had 5.7 times more accidents than the unpainted ones. Exposure data (pedestrian volumes) were collected at a 10 percent sample of these intersections. Marked crosswalks were used 2.9 times more than unmarked crosswalks. Thus, in terms of usage, approximately twice as many pedestrian accidents occurred in marked crosswalks as in unmarked crosswalks. However, before condemning marked crosswalks as being hazardous, one must question whether the marked and unmarked crosswalks at the same intersections are appropriate comparison groups.

At a given intersection one crosswalk may be marked for a variety of reasons, perhaps because of higher anticipated pedestrian volumes or because of the characteristics of the pedestrians who are using that crosswalk. For example, one leg of an intersection may have a crosswalk marking because more high risk pedestrians (the very young or the elderly) use that crosswalk. Similarly, these same high risk pedestrians may go out of their way to use a marked crosswalk while other pedestrians may not do so. The study did report that the very young and the very old had the highest accident incidence in both marked and unmarked crosswalks.

One leg of an intersection may also be marked because of its location relative to specific pedestrian origins and/or destinations (i.e., residences, bus stops, stores, bars, etc.). The study also reported differences in time of day and day of week between pedestrian accidents occurring in marked and unmarked crosswalks. For example, 28 percent of the accidents in marked crosswalks occurred from 5 to 7 PM, while the unmarked crosswalks had no accidents during that period. Unfortunately, the pedestrian volume data that were collected were not categorized by age so that the relative hazard of marked and unmarked crosswalks could not be determined for each age group.

These considerations suggest there may be more differences between the marked and unmarked crosswalks other than the presence or absence of crosswalk markings. If so, the use of the crosswalk pairs may not be appropriate for making such comparisons.

Although the San Diego study is frequently misquoted as having indicated that crosswalks are dangerous and should not be used, such is not the case. The report ended with the following statement:

> "In conclusion, it is appropriate to restate that marked crosswalks will continue to be a useful traffic control device. But it is important that the general public recognize what marked crosswalks can and cannot do. It is also important that public officials not install them unless the anticipated benefits clearly outweigh the risks discussed in this report."

Purpose

Because of the misunderstanding and confusion regarding the use of crosswalk markings in the United States, a set of guidelines for their use is sorely needed. The guidelines should be based on past research and on the experience of practicing engineers. The guidelines are needed for the following specific reasons, to:

- Increase the uniformity of crosswalk application across the country.
- Provide guidance to those who have not yet formulated a policy on where to apply crosswalk markings and to those who are unsure about their current practices.
- Prevent the misapplication of markings in places where they could constitute a safety hazard or where the cost of installation and maintenance is not generally justified.
- Prevent the unnecessary proliferation of crosswalk markings and the resultant increase in disregard for crosswalks in general.

It must be emphasized that crosswalk markings are not a substitute for other types of pedestrian accident countermeasures. One cannot simply stripe a crosswalk and expect an accident problem to clear up. Pedestrian refuge islands, improved signalization, and other strategies are often needed to address the safety problem directly.

Procedure

The goal of the project was to develop a set of guidelines based on current research information that would be accepted and used by the practicing traffic engineer. To achieve this goal, a reiteration process was used. First, a set of draft guidelines was developed. The draft guidelines were based on current practices as identified during a literature review, a survey of local practitioners, and an examination of relevant pedestrian research. The draft guidelines were then reviewed by approximately 30 practitioners and, based on their comments, a final set of guidelines was prepared.

Current Practices

To determine the current operational practice pertaining to the installation of crosswalk markings, nine local practicing traffic engineers were contacted. They were asked the following questions:

- What general warrants, guidelines or criteria do you use to determine where marked crosswalks should be installed?
- What specific warrants, guidelines or criteria do you use to determine whether marked crosswalks should be installed at these specific types of locations?
  - Signalized intersections with pedestrian signals.
  - Signalized intersections (with no pedestrian signals).
  - Unsignalized intersections.
  - School crossings.
  - Midblock crossings.
- What warrants, guidelines or criteria do you use to select locations for the installation of pedestrian signals?
- What warrants, guidelines or criteria do you use to select locations for the installation of push-button activated pedestrian signals?
- What type of crosswalk markings do you use?
  - Double parallel lines.
  - Double parallel lines with diagonal stripes.
  - Double parallel lines with perpendicular longitudinal lines.
  - Textured pavement.
  - Other, specify.
- What warrants, guidelines or criteria do you use to determine which type of crosswalk marking should be used at different types of crosswalk locations?

- Have you had any problems or difficulties using any of these warrants, guidelines or criteria?

- What factors do you think should be considered in developing new warrants, guidelines or criteria?

- What additional information (i.e., pedestrian volume counts) would you be willing to collect if the information were needed to use a newly developed crosswalk marking warrant?

- Are you aware of other warrants or guidelines used by other agencies for the installation of crosswalk markings? If so, who could we contact to obtain this information?

- Are you planning any crosswalk marking projects in the next 6 to 9 months that we could use as a "case study"?

Nine other individuals were asked for the following information on research to demonstrate the safety benefit of crosswalk markings or the effectiveness of crosswalk marking design:

- Have you conducted any research or operational studies to determine:
  - The effectiveness of crosswalk markings in improving pedestrian safety?
  - The most effective type of crosswalk marking design?
  - The most effective type of pedestrian signal design?

- Are you aware of any other agencies that have conducted research addressing any of the above topics?

- Are you aware of any specific warrants, guidelines or criteria being used to determine whether marked crosswalks should be installed at these specific types of locations?
  - Signalized intersections with pedestrian signals.
  - Signalized intersections (with no pedestrian signals).
  - Unsignalized intersections.
  - School crossings.
  - Midblock crossings.

- Are you planning any crosswalk marking projects in the next 6 to 9 months that we could use as a "case study"?

Results

Written responses were received from seven of the eighteen individuals; six more were contacted by telephone. Few of the respondents use specific, quantitative procedures for the application of crosswalk markings or pedestrian signals. As one respondent noted, "engineering judgment" is used to identify sites for crosswalk markings.

All of the respondents mark crosswalks on school routes. The majority of the respondents mark crosswalks at signalized intersections and most install pedestrian signals at all signalized intersections. Crosswalks at unsignalized intersections are marked if on a school route, on a bus route, or if they have complex geometry requiring pedestrian direction. Roadway functional classification was mentioned by one respondent -- all major arterials, collector/distributors, and roadways within the central business district (CBD) are marked. Three respondents indicated that they consider pedestrian volumes, but only one quantified the warrant at 100 ped/day. However, that respondent stated that few intersections would meet this criterion.

With regard to warrants used to select locations for the installation of pedestrian signals, the majority of respondents indicated that all signalized intersections have pedestrian signals. One respondent uses gap analysis, another uses MUTCD warrants, and another installs pedestrian signals within the CBD. The majority of respondents use the push-button activated pedestrian signal where the traffic signals are vehicle actuated. One uses only push-button signals, while two use only fixed time pedestrian signals.

The majority of respondents use double parallel line crosswalks; however, diagonal markings (zebras) are used where traffic volumes are heavy, on school routes, or wherever there is a high concentration of children.

No respondent expressed any problems with using his/her guidelines. Factors recommended for inclusion in a new crosswalk warrant included: urban/rural definitions, traffic and pedestrian volumes, vehicle speed, sight distance, turning movements, school children, and accidents.

Most respondents were not willing to collect additional data, but would do so "if necessary." No respondent had conducted research or operational studies pertaining to crosswalk markings.

Relevant Research

Several sources of information were used for establishing the initial set of guidelines. The first consisted of data from a 1983 study of pedestrian exposure to accidents (Tobey, Shunamen, & Knoblauch, 1983). In that study, data were collected on pedestrian and vehicular volumes, pedestrian accidents, and other site characteristics at numerous intersections in the United States. One element of the analysis of crosswalk markings involved a comparison of scatter diagrams of pedestrian and vehicular volumes at marked and unmarked crosswalks. It was hypothesized that one would find a pattern emerging of crosswalks being marked at locations with higher pedestrian and vehicular volumes and not marked at locations with lower volumes. Although this was true in general, there was considerable overlap in the volume levels for marked and unmarked crosswalks. Marked crosswalks were sometimes found at very low volume levels and unmarked crosswalks were found at high volume levels. Figure 6 shows the volume distributions for the local street sample.

The data in figure 6 indicate how practitioners and decision makers have determined where crosswalks should be marked in the past. If we assume that their judgments are reasonably good, an analysis of the data could be performed to derive an optimum volume threshold curve to use as part of the crosswalk guidelines. This analysis was conducted by fitting several trial curves through the data and identifying which curve minimized alpha and beta error. Alpha error would exist when a marked crosswalk fell below the volume threshold curve. Beta error would exist when an unmarked crosswalk fell above the volume threshold curve.

Logic dictated that the volume threshold curves have a minimum vehicular and pedestrian volume and be convex with respect to the origin. Using this general shape and minimizing alpha and beta error, a basic threshold curve was established. This curve is approximately equivalent to the curve in the recommended set of guidelines. Additional curves were established with lower thresholds to cover wider streets and locations with higher proportions of young, elderly, and handicapped pedestrians.

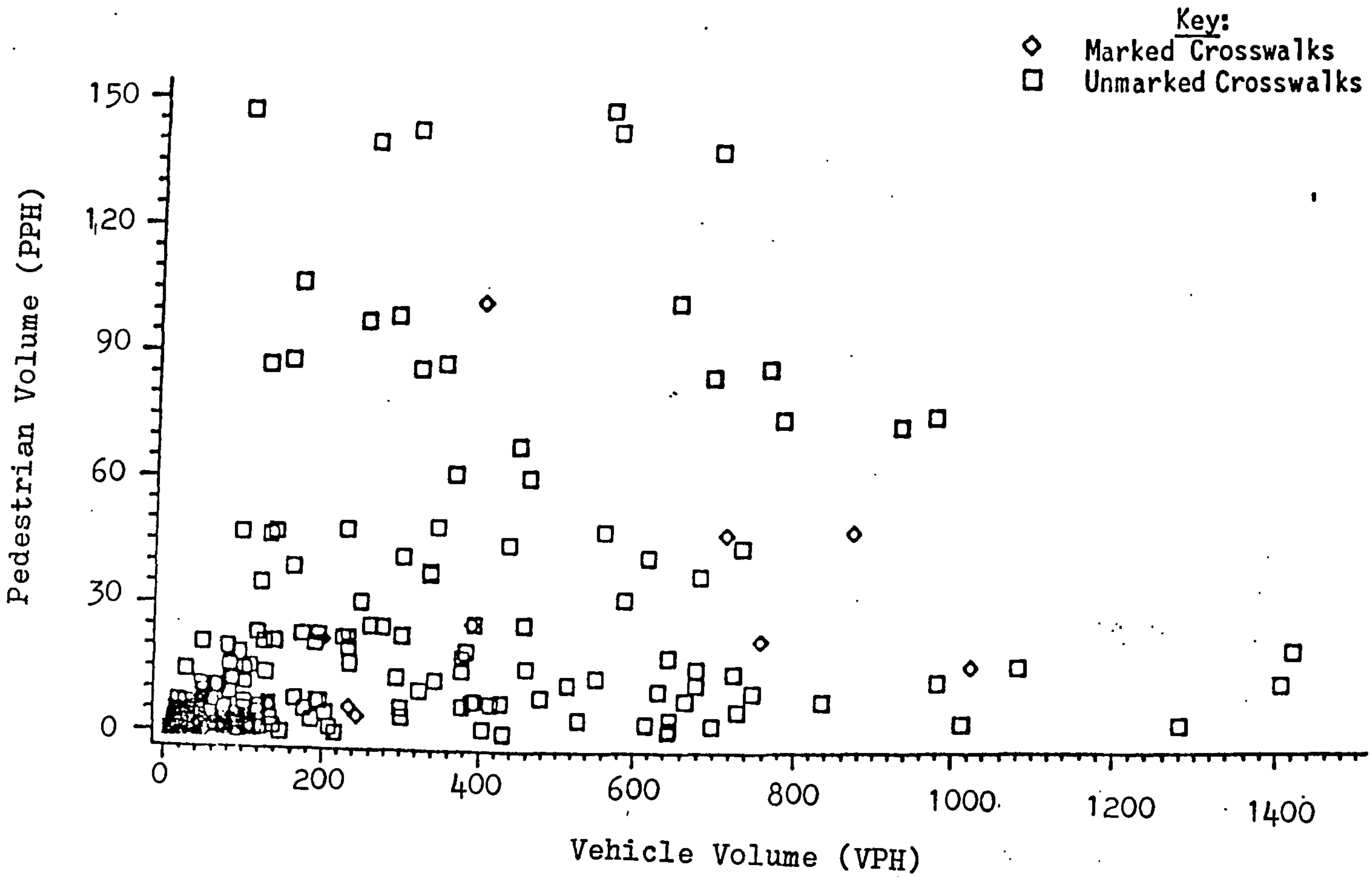


Figure 6. Pedestrian and vehicle volumes of marked and unmarked crosswalks at unsignalized local street intersections (from Tobey, Shunamen, & Knoblauch, 1983).

A second source of information used in establishing the volume threshold curves consisted of existing warrants from outside the United States. Figure 7 was prepared for a South African study (Ribbens & Bahar, 1981) indicating warrant threshold curves proposed or already in use in Australia, Israel, and South Africa. The curves illustrate the vehicle and pedestrian volume thresholds for midblock pedestrian crossings. The thresholds are generally higher than in the suggested guidelines for the United States. This reflects the fact that U.S. pedestrian volumes are typically lower than those abroad. However, the overall philosophy of volume-based thresholds is the same, and the thresholds are of the same order of magnitude.

Practitioner Review

The information gathered during the practitioner survey and the analysis of relevant research was used to generate a preliminary series of warrants for crosswalk markings. Through an iterative process, a draft set of guidelines was developed to be both responsive to the needs of local practitioners and sensitive to available research. This draft set of guidelines was sent to practitioners from the engineering and research communities for review.

In all, 30 engineers were contacted. Each person was sent a draft copy of the guidelines and a form that asked questions about specific parts of the guidelines as well as questions about the acceptability of such guidelines. The form is shown in figure 8. A total of 19 responses was received.

To the first question, regarding the necessity of a set of guidelines for the installation of crosswalk markings, 79 percent of the group felt guidelines were necessary, while 21 percent did not. The reasons for having guidelines as well as the potential benefit of guidelines to State and local agencies centered around the reasons established in the guidelines themselves. Thirty-three percent of the respondents felt increased uniformity of crosswalk application was a principal benefit/reason for having guidelines. Fifteen percent felt the guidelines would help jurisdictions who have not yet formulated policies or are unsure about their current practice regarding crosswalk installations. Fifteen percent of the group also thought that

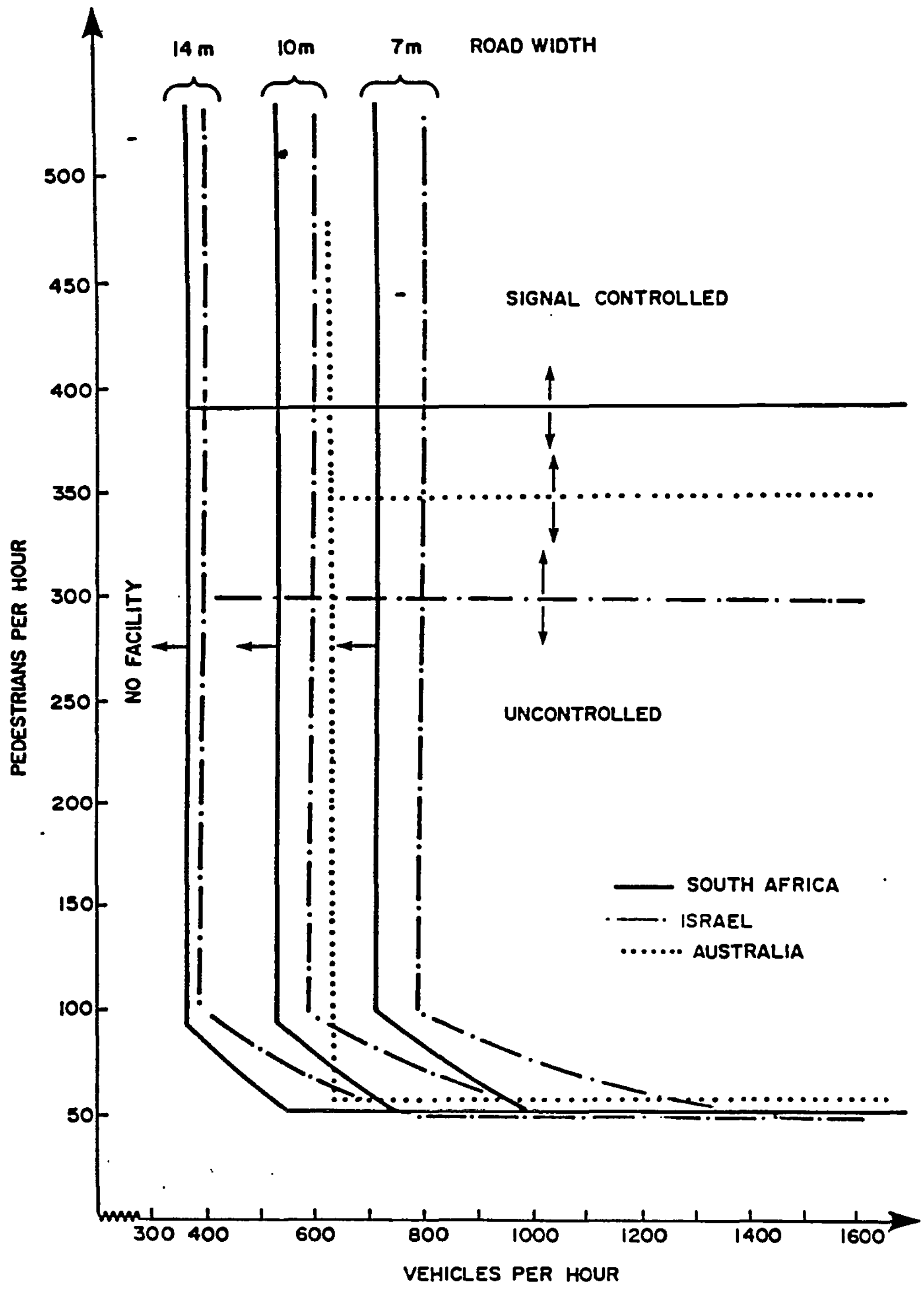


Figure 7. Warrants for midblock pedestrian crossings: South Africa, Israel, and Australia (from Ribbens & Bahar, 1981).

CROSSWALK MARKINGS

1. Do you think that guidelines are needed for the installation of crosswalk markings? Why? ______

______

______

2. How would the guidelines be of benefit to state and local agencies?

______

3. Are the guidelines presented in a format that is usable? How could the format/presentation be improved? ______

______

4. Do the guidelines reasonably reflect where you think crosswalks should and should not be installed? ______

______

   a. Is the concept of volume based warrants valid? ______

   ______

   b. Are the minimum volume thresholds reasonable? ______

   ______

   c. Are the basic criteria appropriate? ______

   ______

5. Is there a need for different types of crosswalk marking configurations? ____ Should the more visible designs be used only in special situations? ____ Should all crosswalks be marked in the same way? ____

______

6. Would the existence of a nationally suggested set of guidelines affect your concern over fort liability claims? ____ How?

______

______

7. How would the application of these guidelines affect current practice? Would you expect fewer, more or about the same number of crosswalks to be installed? ______

______

8. Any comments, compliments, or complaints? ______

______

Completed by:
Name: ______
Position: ______
Phone: (____) ______

Figure 8. Practitioner response form.

guidelines would prevent the proliferation of crosswalk markings. Six percent of the respondents felt guidelines would prevent misapplication of crosswalk markings.

Other reasons were cited besides those given in the background information. Seventeen percent of the group felt guidelines would help them deal with citizen or political requests for crosswalk installations. A corollary of this was cited by 8 percent of the group, who felt guidelines would help organize the decision-making process regarding crosswalks. Three percent felt guidelines would help jurisdictions defend themselves against tort claims.

The third question asked if the guidelines were presented in a usable format. Seventy-four percent of the group felt the guidelines were in a usable format. The remaining 26 percent did not directly answer "yes" or "no." Among the suggested changes to the format were: use of a table rather than a nomograph to establish placement; separate nomographs (one for young and elderly and one for other adults); and the use of diagrams, pictures, and examples.

The fourth question asked about specific details of the guidelines. The first part of the question asked if the guidelines were a reasonable reflection of where crosswalks should or should not be installed. Fifty-eight percent of the respondents felt the guidelines reasonably reflected placement location, while 11 percent did not. Thirty-two percent of the group did not answer "yes" or "no." Two of the respondents felt overall the guidelines might be a little too lenient and that local preferences would require more crosswalks than the guidelines might allow. Two other respondents felt crosswalks are not necessarily needed at signalized intersections with pedestrian signal heads. One jurisdiction indicated the guidelines were in conflict with its standard practice of marking crosswalks at signals, regardless of the presence or absence of pedestrian signal heads. Two jurisdictions responded that the proposed guidelines were similar to their current practice.

The second part of the question asked if basing a warrant on volumes was a valid concept. Seventy-nine percent of the group felt a volume-based warrant is valid, while 5 percent (one jurisdiction) did not. Sixteen percent did not specify either "yes" or "no." Two of the jurisdictions felt basing the volume warrant on pedestrian and vehicle volumes was a good idea. Some individual comments on the question were: there is no research to back up the concept of volume-based warrants; volumes seem appropriate because we (the local agency) cannot refute them; volume-based warrants alone are not enough; and why not use volume-based warrants since gap theory has not been the answer.

The third part of question 4 asked about the reasonableness of the minimum volume thresholds. Forty-eight percent of the group felt the minimum volumes were reasonable, while 26 percent did not. Twenty-six percent did not specify a "yes" or "no" answer. This question generated several comments from the group. Three respondents felt the volumes were generally too high and possibly not reflective of rural or suburban needs. Two other jurisdictions felt the volumes were generally too low. One comment was the volumes may need to be a local policy decision. One person felt the pedestrian volume should be based on a peak hour count and not the average over the peak 4 hours. The reason for this is balanced against the labor/time that it takes to get the pedestrian data; it is easier just to install the crosswalk. Two individuals felt a crosswalk should not be installed at an unsignalized location with high traffic volumes and low pedestrian volumes. Another jurisdiction felt the high and low ends of the nomograph were arbitrary and had no empirical basis.

The fourth part of question 4 asked about the appropriateness of the basic criteria. Seventy-nine percent of the group felt the basic criteria were appropriate, while the remaining 21 percent did not give a "yes" or "no" reply. Three respondents mentioned that pedestrian accident data might be a useful part of the basic criteria. Two jurisdictions felt the midblock crossing block length criterion of 600 feet was not always appropriate and perhaps this criterion would be better referred to as the preferred block length. One jurisdiction felt the "no conflicting attention demands criteria" would be better stated using the word "minimal" in place of "no." Another respondent felt the addition of a criterion to ensure removal of parking on the approach leg would be an improvement.

The fifth question concerned different types of markings. The first part of the question concerned the need for different markings. Sixty-three percent of the group felt different types of markings were needed, while 26 percent did not. Eleven percent did not respond. Responding to the second part of the question, 68 percent of the respondents thought the more visible crosswalks should be used for special situations. Eleven percent did not, and 21 percent did not respond. To the third part of question 5, 26 percent of the group felt all crosswalks should be marked the same way, while 63 percent did not. Eleven percent did not respond. Several respondents felt the same markings should be used for the same situation. One jurisdiction felt each case should be treated separately. Three respondents thought school crosswalks should be marked differently and one felt midblock crossings should use a more visible configuration. One jurisdiction felt crosswalk markings should become a uniform standard for ready recognition by pedestrians and motorists. One individual thought a standardized crosswalk marking was a good idea if any configuration other than just two parallel lines was used. One jurisdiction only uses zebra crossings at unusual or poorly lit locations. One person felt that from a driver's standpoint, there appears to be no gain from using different configurations.

The sixth question was about tort liability. Fifty-three percent of the group felt a nationally suggested set of guidelines would affect their concerns about tort liability, while 31 percent did not. Sixteen percent did not answer with a "yes" or "no." For those who cited concerns, some would have heightened anxiety while others would feel less anxious. Three respondents felt there would be no tort problems as long as the "guidelines" remained guidelines and not standards. Three jurisdictions felt the guidelines would improve tort problems by showing local conformity with an adopted practice. Three individuals expressed concern over a situation where the guidelines would not require a crosswalk, over time the field conditions change, an accident occurs, and the local jurisdiction is ripe for suit. Two respondents felt that to have any formal policy causes a jurisdiction to be on the defensive as an established procedure may encourage litigation.

The seventh question asked how current practice would be affected by the guidelines. Thirty-two percent of the group expected they would install fewer crosswalks under the guidelines. Twenty-six percent felt they would install more crosswalks, and 26 percent thought they would place about the same number as they do currently. Twenty-one percent of the group did not respond.

The eighth question provided the group an opportunity to make general comments. Five members of the group felt this area needs attention. One person felt the guidelines are somewhat contradictory in that the principles appear to limit the proliferation of crosswalks, while the guidelines seem to increase their use. One comment was the guidelines should allow for the exercise of engineering judgment. Another respondent felt the guidelines could have a positive effect on pedestrian accidents, but they could also possibly increase litigation.

The comments and suggestions made by the reviewers were considered when preparing the final set of guidelines.

Recommended Guidelines for Crosswalk Markings

The development of a reasonable and succinct set of guidelines required that a set of basic criteria be postulated:

- Crosswalks should not be marked where crossing the street may be unusually dangerous (e.g., locations with high traffic speeds, poor sight distance, or poor illumination).
- In light of the installation and maintenance costs of pavement markings, crosswalk markings should be located at places expected to receive sufficient benefit. This suggests that crosswalks with low vehicular volume and/or low pedestrian volume do not warrant markings. The determination of minimum pedestrian and vehicle volume thresholds are an important part of establishing reasonable guidelines for installation of crosswalk markings.
- Guidelines for installing crosswalks should include the type of pedestrians expected to be crossing the street. Lower volume thresholds should be considered for areas where there is a greater proportion of less experienced and less agile pedestrians (e.g., near schools and/or elderly housing areas).

- Crosswalk markings in higher-risk crossing areas (higher traffic volumes and speeds) should be supplemented by advance warning signs and, in some cases, advance warning pavement markings.

- Crosswalks should be used selectively. Allowing a proliferation of crosswalks reduces the overall effectiveness of each crosswalk.

- Specific variables that should be considered when locating crosswalks include: activities located nearby (e.g., schools, shopping), pedestrian volume, vehicular volume, sight distance, vehicular speeds, street width and presence of a median, one-way versus two-way operation, and geometrics of the highway or intersection being crossed.

The draft guidelines were developed based on these basic criteria. After being reviewed by the practitioners, the draft guidelines were modified to reflect their comments and suggestions. The final guidelines for installing crosswalk markings are as follows.

Crosswalk markings should be installed at:

- All signalized intersections with pedestrian signal heads.

- All locations where a school crossing guard is normally stationed to assist children in crossing the street.

- All intersections and midblock crossings satisfying the minimum vehicular and pedestrian volume criteria in figure 9. As long as the basic criteria governing sight distance, speed limit, etc., are met, a crosswalk is deemed appropriate if the pedestrian and vehicular volumes place it above the appropriate curve in figure 9. Each crosswalk is analyzed by approach leg, indicating that a crosswalk might be warranted on one side of an intersection and not the other. Thus, the guidelines might suggest that only one crosswalk need be marked at a given intersection. If each approach warranted a crosswalk, then all would be marked.

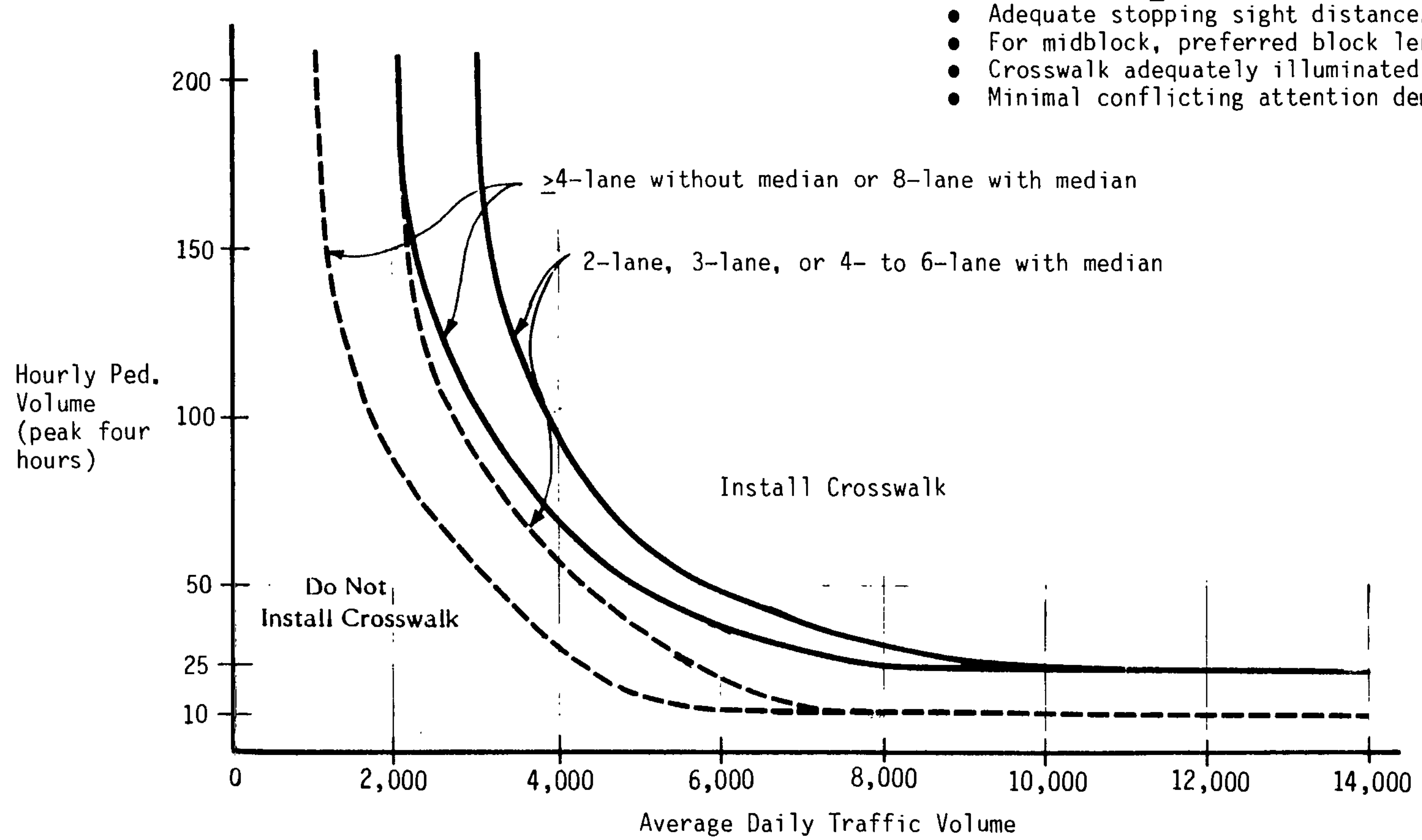
- All other locations where there is a need to clarify the preferred crossing location when the proper location for crossing would otherwise be confusing.

The most important elements of the guidelines are the basic criteria, which place some restrictions on crosswalk applications to prevent their being placed in locations that would be extremely hazardous to the pedestrian. Placing crosswalks in locations with high speeds or poor sight distance is

--- = Locations with predominantly young, elderly or handicapped pedestrians
___ = Other locations

Basic Criteria

- Speed limit ≤ 45 mi/h.
- Adequate stopping sight distance.
- For midblock, preferred block length ≥ 600'.
- Crosswalk adequately illuminated.
- Minimal conflicting attention demands.



1. If using only the peak hour, threshold must be increased by 1.5
2. For streets with a median, use one-way (directional) ADT volume.

Other notes: Minimum striping is 6" parallel lines. Consider bolder markings and/or supplementary advance markings or signing at uncontrolled locations where speed limits exceed 35 mi/h.

Figure 9. Guidelines for crosswalk installation at uncontrolled intersection legs, midblock crossings, and signalized intersections without ped heads.

never advisable. A crosswalk is not a solution to situations such as this, and other preventive measures should be carefully considered.

It will generally be difficult to reach the pedestrian volume thresholds in suburban areas. This is viewed to be an advantage to the pedestrian, as it will result in more selective use of crosswalk markings, which should result in improved compliance with the markings in general. Crosswalk markings should not be so commonplace that drivers lose appreciation of their purpose.

The volume thresholds are reduced for locations where young, elderly, or handicapped pedestrians are a significant proportion of the pedestrian population. A value of 50 percent or more is suggested, but this is best left to the judgment of the engineer.

At uncontrolled intersection legs and midblock crossings with speed limits of 40 to 45 mi/h, the guidelines suggest the placement of more visible markings for greater conspicuity for drivers. All crossings at uncontrolled intersection legs and midblock crossings should be supplemented with crosswalk signs, as indicated in the MUTCD.

Discussion

Another element of the evaluation involved a comparison of the pedestrian volume thresholds with other related warrants and criteria. A new pedestrian warrant has also been recommended for the installation of traffic signals and is presently under consideration by the National Committee on Uniform Traffic Control Devices. The new warrant suggests a minimum pedestrian volume of 100 pedestrians per hour for each of 4 hours and requires minimum gaps (less than 60 per hour) in traffic as well. The current minimum volume requirements in the MUTCD for warranting a traffic signal are 150 pedestrians per hour in the same hours for which the peak 8 hours of vehicular volume occur. This may be reduced by 70 percent where speeds are above 40 mi/h. If adopted, the lower pedestrian volume threshold would replace the above criteria, making it easier to justify a signal on the basis of pedestrian volume. However, justifying a signal on the basis of pedestrian volume would still be rare.

The recommended crosswalk marking guidelines appear to be reasonable when compared with the volume thresholds for other warrants. One would expect the volume threshold for crosswalk markings to be considerably lower than for warranting traffic signals or pedestrian signals. Although the warrants are written to be applied in all land use settings, there could be a rationale for increasing the minimum volume thresholds in more densely developed settings to prevent too great a proliferation of markings. Local adjustments to the minimum thresholds may need to be considered as experience is gained.

The recommended guidelines for crosswalk markings fill a significant void in the treatment of crosswalks nationwide. If widely applied, they will greatly improve the consistency with which markings are applied and ultimately produce a more cost-effective allocation of resources. However, they should not be viewed as significantly addressing the pedestrian safety problem. Many other techniques exist in education, engineering, and enforcement to more directly address safety concerns. Crosswalk markings are primarily a discipline tool, providing a degree of recognition of pedestrians and informing them of proper crossing locations.

One of the major concerns in pedestrian safety is the general lack of respect by drivers of pedestrian rights. Most State laws provide pedestrians with substantial rights, especially at marked crosswalks, but there is little observance of those rights in practice. Better enforcement is one of the few processes available to produce better driver observance of pedestrian rights at crosswalks. In reality, however, it is not expected that observance will improve or that increased enforcement will be provided. Therefore, better discipline and consistency is needed in the marking of crosswalks. The proposed guidelines should help to accomplish this objective.

CHAPTER III
IMPROVEMENTS TO MAJOR ARTERIAL STREETS

INTRODUCTION

This chapter summarizes the activities involved in Task B, the investigation of improvements to major arterial streets for pedestrian safety. The task involved identifying the safety and operational problems faced by pedestrians in urban and suburban areas on major arterials and identifying engineering approaches to ameliorate these problems. Three principal activities were carried out to achieve the goals of the task:

- Analysis of pedestrian exposure data.
- State-of-the-practice review.
- Case studies of candidate improvements.

The exposure data analysis involved an in-depth investigation of the exposure data collected in the previous FHWA research project, "Pedestrian Trip Making Characteristics and Exposure Measures." The purpose of the analysis was to identify the characteristics associated with major arterials that were particularly hazardous for pedestrians, as well as to determine the characteristics that made the major arterial environment a safe one for pedestrians.

The state-of-the-practice review involved contacting local officials to determine the current state-of-the-practice in providing for a safe pedestrian environment on major arterials in urban and suburban areas. These contacts were used to determine what engineering techniques are used by practicing traffic engineers (i.e., signalization, pathways, medians, midblock pedestrian barriers, widening roadway delineation, signal retiming, etc.).

The final activity in this task involved evaluations of candidate improvements on major arterial highways. These case studies involved field evaluations of existing improvements in the following four localities:

- Fairfax, Virginia - Old Lee Highway.
- Fairfax, Virginia - Jermantown Road.
- Hamilton Township, New Jersey.
- Baltimore, Maryland.

ANALYSIS OF PEDESTRIAN EXPOSURE DATA ON MAJOR ARTERIALS

Major arterials were selected as a problem area because they had a PxV hazard score of +2.1. This means that while major arterials had 8.1 percent of the pedestrian (P) and vehicle (V) exposure, 17.0 percent of pedestrian accidents occurred on these types of roads. All of the variables pertinent to major arterials were analyzed as discussed below.

Land Use

Although major arterials in commercial/industrial areas had 78.1 percent of the pedestrian exposure and 86.2 percent of the PxV exposure, they also had 67.4 percent of the accidents. Thus, they were not especially hazardous in terms of the PxV exposure measure. However, major arterials in 100 percent residential and in mixed residential areas were hazardous for pedestrians in terms of the PxV exposure measure.

Land Use at Intersection	% of National Projections for Major Arterials of:				Hazard Score		
	Acc.	Sites	Peds	P x V	Site	Peds	P x V
100% Residential	3.6	20.3	4.9	1.8	-5.6	-1.4	+2.0
Commercial/Industrial	67.4	57.4	78.1	86.2	+1.2	-1.2	-1.3
Mixed Residential	29.0	22.3	17.0	12.0	+1.3	+1.7	+2.4

Number of Lanes

Major arterials with more than two lanes had P and PxV exposure in proportion to their accidents. However, major arterials with two lanes or less were hazardous for pedestrians in terms of both the P and the PxV exposure measure.

Number of Lanes	% of National Projections for Major Arterials of:				Hazard Score		
	Acc.	Sites	Peds	P x V	Site	Peds	P x V
Two or Less	11.5	21.4	7.3	5.7	-1.9	+1.6	+2.0
More than Two	88.5	78.6	92.7	94.3	+1.1	-1.0	-1.1

Length of Block

Major arterials consisting of short blocks were more hazardous for pedestrians in terms of the P and PxV exposure measures. However, only 5 percent of the pedestrian exposure and 2.3 percent of the PxV exposure were on major arterials with this short block length. On the other hand, blocks of moderate length were safe for pedestrians in terms of the P and PxV exposure measures. Sites with long blocks were neither safe nor hazardous.

	% of National Projections for Major Arterials of:				Hazard Score		
Length of Block	Acc.	Sites	Peds	P x V	Site	Peds	P x V
Less than 250 ft	26.3	12.8	5.0	2.3	+2.0	+5.3	+11.4
251 ft - 499 ft	26.0	57.8	47.8	35.2	-2.2	-1.8	-1.4
Greater than 500 ft	47.7	29.5	47.1	62.5	+1.6	+1.0	-1.3

Medians

Interestingly, major arterials without medians had a PxV exposure in proportion to their accidents, as did major arterials with medians. Thus, in terms of the PxV hazard score, the presence or absence of medians on major arterials did not affect pedestrian safety. However, a higher percentage of pedestrians were on major arterials without medians and thus had a safe P hazard score. And, the fewer pedestrians on major arterials with medians had a hazardous P hazard score.

	% of National Projections for Major Arterials of:				Hazard Score		
Medians	Acc.	Sites	Peds	P x V	Site	Peds	P x V
No Medians	59.1	75.4	87.2	66.2	-1.3	-1.5	-1.1
Medians	40.9	24.6	12.8	33.8	+1.7	+3.2	+1.2

Roadway Center Marking

It is interesting that major arterials with no center markings or with a single dashed line center marking were safe in terms of the P and PxV exposure measure. Major arterials with a double solid line were hazardous.

Roadway Center Markings	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	9.6	20.6	55.2	40.3	-2.2	-5.8	-4.2
Double Solid Line	52.5	35.7	27.4	21.1	+1.5	+1.9	+2.5
Single Dashed Line	2.0	18.6	4.4	4.3	-9.3	-2.2	-2.2
Other	35.8	25.0	13.0	34.2	+1.4	+2.8	+1.0

Roadway Lane Markings

Major arterials without lane markings were hazardous for pedestrians in terms of the P and the PxV exposure measures. Those with dashed lane markings had P and PxV exposures in proportion to their accidents. Major arterials with dashed and solid lane markings (most likely to occur on two-lane roadways) were hazardous for pedestrians in terms of the P and PxV exposure measures.

Roadway Lane Markings	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	13.5	21.9	8.9	7.3	-1.6	+1.5	+1.8
Dashed	72.6	56.7	88.2	85.3	+1.3	-1.2	-1.2
Dashed and Solid	12.5	21.4	2.9	7.3	-1.7	+4.3	+1.7

Channelization

As might be expected, locations with left turn channelization were hazardous for pedestrians in terms of both the P and the PxV exposure measures. Sites with both right and left turn channelization were also hazardous, but to a lesser degree. Places with right turn channelization and places with no channelization were safe for pedestrians.

Channelization	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	59.3	67.6	88.1	85.3	-1.1	-1.5	-1.4
Left Turn	33.8	18.4	7.0	7.0	+1.8	+4.8	+4.8
Right Turn	1.1	8.9	2.6	5.6	-8.1	-2.4	-5.1
Both Right and Left	5.8	5.1	2.4	2.0	+1.1	+2.4	+2.9

Parking Restrictions

Contrary to the findings for local streets, prohibiting parking on both sides of a major arterial was more hazardous for pedestrians. Where parking is permitted on both sides, or at various times of day, pedestrian safety was increased. This may be because restricting parking may allow for higher vehicle speeds. Also, pedestrians may be unexpected where parking is prohibited.

Parking Restrictions	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Permitted Both Sides	23.7	29.1	47.9	37.1	-1.2	-2.0	-1.6
Prohibited One Side	8.0	28.0	17.2	9.9	-3.5	-2.2	-1.2
Prohibited Both Sides	47.0	26.1	4.9	9.4	+1.8	+9.6	+5.0
Width Restricts to Both Sides/Not Posted	4.3	4.3	2.3	4.2	+1.0	+1.9	+1.0
Restrictions Vary by Time of Day	17.0	12.5	27.6	39.4	+1.4	-1.6	-2.3

Parking Meters

As with parking restrictions, major arterials with parking meters were safe for pedestrians and those without parking meters were hazardous.

Parking Meters	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	89.6	89.4	80.2	65.5	+1.0	+1.1	+1.4
One or Both Sides	10.5	10.6	19.8	34.5	-1.0	-1.9	-3.3

Parking on Premises

Major arterials without businesses with parking on the premises (POP) were safe in terms of both the P and the PxV exposure measures. This may correlate with the findings for parking restrictions and parking meters in that major arterials with no businesses with POP may have on street parking. Or, major arterials without businesses with POP may be safe because of a lack of driveways. Major arterials with POP were hazardous in terms of both the P and the PxV exposure measures.

Parking on Premises (POP)	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
No Businesses with POP	27.5	58.9	63.3	64.0	-2.1	-2.3	-2.3
Businesses with POP	72.5	41.1	36.7	36.0	+1.8	+2.0	+2.0

Pedestrian Accommodations

In terms of the PxV exposure measure, major arterials with sidewalks were not safer than major arterials with no sidewalks. However, in terms of the P exposure measure, major arterials without sidewalks were hazardous while those with sidewalks were neither particularly safe nor particularly hazardous.

Pedestrian Accommodations	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
No sidewalks/pathways	11.9	24.1	5.5	12.2	-2.0	+2.2	-1.0
Sidewalk - One or Both Sides	88.1	75.9	94.5	87.8	+1.2	-1.1	+1.0

Curbs

In terms of the PxV exposure measure, the presence or absence of curbs on major arterials did not influence pedestrian safety. However, in terms of the P exposure measure, major arterials without curbs were hazardous while those with curbs were neither safe nor hazardous. This finding may be related to the fact that many locations with curbs also have sidewalks.

Curbs	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	6.1	10.8	2.8	4.6	-1.8	+2.2	+1.3
One or Both Sides	93.9	89.2	97.2	95.4	+1.0	-1.0	-1.0

Street Lighting

Major arterials without street lighting were hazardous for pedestrians in terms of both the P and PxV exposure measures. Major arterials with regularly spaced street lighting had a PxV score of 1.1. In terms of the PxV exposure measure, major arterials with irregularly spaced street lighting also had a PxV score very close to 1.0 and were therefore neither hazardous nor safe.

Street Lighting	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	11.9	4.8	2.2	2.6	+2.5	+5.4	+4.6
Regularly Spaced	82.7	80.9	94.1	90.5	+1.0	-1.1	-1.1
Irregularly Spaced	5.4	14.3	3.6	6.9	-2.6	+1.5	-1.3

Commercial Lighting

In terms of the P exposure measure, the presence of commercial lighting had no effect on pedestrian safety. In terms of the PxV exposure measure, major arterials with continuous commercial lighting were slightly hazardous. This is compatible with the earlier finding that commercial/industrial areas were found to be hazardous for pedestrians.

Commercial Lighting	% of National Projections for Major Arterials of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	37.9	56.2	36.9	43.4	-1.5	+1.0	-1.2
Continuous	31.2	9.2	28.1	22.5	+3.4	+1.1	+1.4
Not Continuous	30.9	34.5	35.0	34.1	-1.1	-1.1	-1.1

Pedestrian Age

In terms of their exposure, pedestrians in the 1-4, 5-9, and 10-14 age groups were more likely to be involved in accidents on major arterials.

Pedestrian Age	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
01-04	3.0	0.4	+7.5
05-09	9.5	2.0	+4.8
10-14	5.7	4.1	+1.4
15-19	10.3	8.2	+1.3
20-29	23.8	19.5	+1.2
30-59	24.5	45.7	-1.9
60+	23.1	20.1	+1.2

Pedestrian Sex

At all sites, males and females were involved in accidents on major arterials in proportion to their exposure.

Pedestrian Sex	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Male	59.6	61.0	-1.1
Female	40.4	39.0	+1.0

Pedestrian Accompaniment

At all sites, pedestrians traveling alone and pedestrians traveling with others were involved in accidents on major arterials in proportion to their exposure.

Pedestrian Accompaniment	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Alone	55.7	65.7	-1.2
With Others	44.3	34.3	+1.3

Pedestrian Mode

At all sites, running was much more hazardous than walking on major arterials.

Pedestrian Mode	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Walking	68.8	95.2	-1.4
Running	31.2	4.87	+6.5

Crossing Location

As might be expected, crossing in a crosswalk was safer than crossing at other locations on major arterials.

Crossing Location	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Crosswalk	32.6	69.3	-2.1
Within 50 ft of Intersection	13.8	5.4	+2.6
Diagonally Across Intersection	3.2	0.7	+4.6
Midblock	50.3	24.6	+2.0

Signal Response

For major arterials, crossing with the green signal was definitely safer than crossing against the red signal.

Signal Response	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
With Signal: Green	52.1	83.1	-1.6
Against Signal: Red	47.9	16.9	+2.8

Accident Type

Nineteen accident types were included in the exposure data base. For major arterials, however, 12 accident types were not analyzed either because the number of pedestrian accidents or the number of pedestrians observed were too few to draw any sound conclusions. Of the remaining seven accident types, three had negative hazard scores. This indicates that the behaviors associated with these three accident types on major arterials were exhibited by pedestrians who were not involved in accidents more often than they were by pedestrians who were involved in accidents. These behaviors were relatively "safe."

Two accident types, playing in the roadway and intersection dash, had "neutral" hazard scores of +1.1 and +1.2, respectively. The remaining two accident types had positive hazard scores and thus represent hazardous behaviors. The midblock dart-out had, by far, the highest hazard score. Accidents involving pedestrians walking across the major arterial, not at an intersection, were also overrepresented.

Accident Type	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Exiting-Entering Parked Vehicles	1.2	7.5	-6.2
Ped on Sidewalk - Not Crossing	2.8	16.6	-5.9
Intersection Crossing Walking	14.7	47.5	-3.2
Midblock Dart-Out	23.2	1.3	+17.8
Midblock Crossing Walking	24.1	15.9	+1.5
Intersection Dash	9.0	7.6	+1.2
Playing in Roadway	1.2	1.1	+1.1

Vehicle Action

For major arterials, vehicles proceeding straight, turning left or turning right with the signal were involved in about the same number of accidents as they were observed. This is in contrast to the finding that major arterial sites with left turn channelization were hazardous. Vehicles making right turns on red (RTOR) were involved in six times as many accidents as they were observed making the RTOR. However, this finding was based on a very small sample size.

Vehicle Action	On Major Arterials, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Going Straight	86.5	88.7	-1.0
Turning Right	4.4	5.1	-1.2
Turning Left	6.2	5.7	+1.1
Right Turn on Red	3.0	0.5	+6.0

Summary

For five of the factors analyzed, both the P and the PxV hazard scores were classified as hazardous, safe, or neutral for each characteristic. This means that the distribution of the pedestrian exposure among the factor's characteristics is similar to the distribution of the PxV exposure among the factor's characteristics. These five factors were:

- Number of Lanes.
- Block Length.
- Center Markings.
- Lane Markings.
- Parking on the Premises.

Considering both the P and the PxV hazard scores, the following general conclusions were made for major arterial streets.

- Mixed residential areas were more hazardous for pedestrians.

- Major arterials with two lanes or less were more hazardous for pedestrians. Similarly, those with double solid center lines, or with no lane markings, were more hazardous.

- Major arterials with more than two lanes were neither safe nor hazardous. Similarly, in terms of the PxV exposure, major arterials with medians were neither safe nor hazardous.

- Left-turn channelization or both right- and left-turn channelization was hazardous for pedestrians. Major arterials with no channelization or with right-turn channelization only was safe for pedestrians.

- In general, sites where parking is prohibited on major arterials were hazardous and sites where parking is permitted were safe. Similarly, major arterials with parking meters were safe, and those without parking meters were hazardous. Again, major arterials without POP (and perhaps with on-street parking) were safe and those with POP (and perhaps without on-street parking) were hazardous. The latter may be due to others factors, e.g., the frequency of driveways.

- In terms of the PxV exposure measure, the presence or absence of sidewalks or curbs did not affect pedestrian safety. However, in terms of the P exposure measure, the absence of sidewalks or curbs was hazardous, while their presence was neither safe nor hazardous.

- In general, major arterials without street lighting were hazardous and those with street lighting were neither safe nor hazardous.

STATE-OF-THE-PRACTICE REVIEW FOR MAJOR ARTERIAL STREETS

Nine local practitioners were contacted to determine those pedestrian safety measures currently in use on major arterials. Seven responses were received.

The practitioners were asked to express their opinions on the potential effectiveness of the 11 pedestrian safety measures. The responses were averaged as follows: 1 - "Very Effective," 2 - "Limited Effect," 3 - "Not Effective," 4 - "Potentially Harmful." The average responses are shown below.

Pedestrian Safety Measure	Average Reponse
Sidewalks or Pathways	1.0
Pedestrian Activated Signals	1.4
Crosswalks: Signalized Intersections	1.4
Street Lighting	1.8
Right Turn Restrictions	1.8
Median Barriers: Restrict Midblock	2.0
Left Turn Restrictions	2.2
Curbside Barriers: Restrict Midblock	2.4
Crosswalks: Unsignalized Intersections	2.6
Reduced Speed Limits	2.6
Pedestrian Crossings: Midblock	3.3

The pedestrian safety measures considered to be most effective by the seven respondents were:

- Sidewalks or Pathways.
- Crosswalks: Signalized Intersections.
- Pedestrian Activated Signals.
- Street Lighting.
- Right Turn Restrictions.

Only one pedestrian safety measure, "Pedestrian Crossings: Midblock," had an average score greater than 3.0, indicating it is perceived as not effective to the point of being potentially harmful.

The respondents were asked to identify those safety measures that they have used (or plan to use) to enhance pedestrian safety on major arterials. Four of the seven respondents indicated that they have used these three safety measures:

- Sidewalks or Pathways.
- Pedestrian Crosswalks: Signalized Intersections.
- Pedestrian Activated Signals.

All of the other pedestrian safety measures were listed as being used by at least one respondent.

The local practitioners were also asked "What specific warrants, guidelines, and/or criteria do you use to determine whether crosswalks should be installed at the following types of locations on major arterials?" Five responses were received.

Signalized Intersections with Pedestrian Signal

Three respondents mark all of these intersections; two respondents consider pedestrian volumes, school routes, and/or the presence of sidewalks.

Signalized Intersections (with No Pedestrian Signals)

One respondent indicated that all signalized intersections have pedestrian signals and are marked. One respondent only marks those with pedestrian signals. Three respondents consider pedestrian volume and/or school routes.

Unsignalized Intersections

One respondent marks no unsignalized intersections. Four respondents consider pedestrian volumes, presence of sidewalks, and/or school routes.

Midblock Locations

Two respondents have no midblock crossings. One respondent marks midblock crosswalks if signalized, and two respondents consider pedestrian volume.

School Crossings

Two respondents mark all school crossings; one respondent marks them if signalized; and two respondents consider pedestrian volumes, vehicle speeds, and/or sight distances.

The local practitioners were asked: "What specific warrants, guidelines and/or criteria do you use to determine whether pedestrian signals should be installed on major arterials?" All of the five respondents indicated the MUTCD. Other criteria included pedestrian volumes and sight distances.

CASE STUDY: OLD LEE HIGHWAY, FAIRFAX, VIRGINIA

Summary

This case study evaluated a unique pedestrian signal located at the intersection of Old Lee Highway and Old Post Road and activated for a 3-hour period in the afternoon. The top and bottom signal heads contain yellow lights that flash alternately and the middle signal head contains a red "X." One pedestrian signal is placed on each approach to Old Post Road. The crosswalk on the northern leg of the intersection is marked. Vehicle speed data were recorded at this marked crosswalk and at two adjacent marked crosswalks to determine the effect of the activated signal on vehicle speeds. Pedestrian counts and crossing locations were recorded.

Background

Old Lee Highway, State Route 237, runs northeast-southwest through Fairfax City, Virginia. At the study site, Old Lee Highway is a two-lane roadway with shoulders. Old Lee Highway widens to a four-lane roadway approximately 0.25 mile southwest of Old Post Road and approximately 1 mile northeast of Old Post Road. Old Post Road is located on a slight hill. Vehicle counts on Old Lee Highway were made by Fairfax City on May 29, 1984 just south of Old Pickett Road, approximately 1 mile northeast of Old Post Road. The number of southbound vehicles was 8,315 and the number of northbound vehicles was 7,287 for a total 24-hour volume of 15,602.

The pedestrian signal was installed as one of the improvements made to Old Lee Highway following a pedestrian fatality at this location in 1982. Other improvements included the restriping of crosswalks in a laddered pattern and a speed limit reduction from 35 to 30 mi/h.

Housing developments exist on both sides of the roadway at the site. A community swimming pool is located on the southeast side. Fairfax High School is located on Old Lee Highway approximately 0.5 mile northeast of Old Post Road and two elementary schools, Layton Hill and St. Leo's, are located about 1000 feet southwest of Old Post Road. A school speed limit sign with flashing beacons is located at these schools just southwest of the pedestrian signal. This school signal operates from 7:30 to 9:45 AM and 2:30 to 4:15 PM.

The pedestrian signal at Old Post Road is located between two marked crosswalks. One marked crosswalk is approximately 1000 feet southwest of Old Post Road adjacent to the elementary schools and thus within the school speed zone as defined by the location of school signals. The other marked crosswalk is approximately 1000 feet northeast of Old Post Road at the intersection of Old Lee Highway and Brookwood. No signals are present at this crosswalk.

Study Objective

The objective of the case study was to determine the effect of the pedestrian signal on vehicle operations, measured in terms of vehicle speed and pedestrian behavior. Specifically, the study was designed to determine the following:

- Difference in vehicle speeds at the three crosswalks when the pedestrian signal is operating and not operating.
- Difference in vehicle speeds at the three crosswalks when the school signal is operating and not operating.
- Difference in vehicle speeds at the three crosswalks when the pedestrian signal and the school signal are operating simultaneously.
- Pedestrian looking behavior.
- Pedestrian crossing location.
- Numbers and ages of pedestrians crossing Old Lee Highway.

Data Collection

Data were collected for 4 days in May, June, and July 1985. School was in session during 2 of the data collection days; during the other 2 days school was not in session and the school signal was not operating. The following data were collected at each of the three crosswalks for vehicles traveling in both directions on Old Lee Highway: free flow vehicle speed when only the pedestrian signal was operating, when only the school signal was operating, when both the pedestrian signal and school signal were operating, and when neither signal was operating. Vehicle speeds were measured at each of the three crosswalks; presence of pedestrians for each vehicle speed measured; numbers of pedestrians crossing Old Lee Highway.

Results

The purpose of the pedestrian observations was to determine what effect the pedestrian signals have on pedestrian behavior. Thus, only pedestrians who were not crossing with the assistance of an adult crossing guard were counted. Only 41 such pedestrians were observed during 4 days of data collection, so elaborate statistical analysis is not appropriate. Although each of the crosswalk locations had roughly comparable numbers of pedestrians, none of the crosswalk locations had high compliance rates. Overall, only one-fourth of the pedestrians crossed totally or partially in the crosswalk. Over one-third crossed within 50 feet of a crosswalk and another third crossed more than 50 feet from a crosswalk. An estimate of pedestrian looking behavior was made by looking at pedestrian head-turning behavior. Nearly 40 percent of the pedestrians did not turn their heads in a scanning motion prior to or during the crossing. The pedestrians were about equally divided between the 7-12, 13-19, and 20-and-over age categories, a distribution no doubt affected by the proximity of the three schools.

Vehicle speeds were measured to determine the effect of the special pedestrian signal and the school signal on driver behavior. A 3x3 (signal operation x crosswalk location) analysis of variance was calculated for vehicle speeds. The mean vehicle speeds at each of the three crosswalks by signal operation are shown below. The crosswalk with the pedestrian signal had the lowest vehicle speeds even when the signals were not activated. This is possibly because the crosswalk is located at a slight hillcrest. The activation of the pedestrian signal produced a slight, but not statistically significant, reduction in vehicle speed. When both the school signal and the pedestrian signal were activated, the mean speed was reduced 4.5 mi/h at the pedestrian signal crosswalk and 4.0 mi/h at the school signal crosswalk; both of these differences are significant. The pedestrian signal alone did not produce a significant change in speed.

Signal Operation	Mean Speed at Each Location (mi/h)		
	No Signal	Pedestrian Signal	School Signal
None	34.8	32.8	35.6
Pedestrian Signal Only	34.9	32.1	35.1
Pedestrian & School Signal	34.3	28.3	31.6

To determine the effect of the school signal alone, a limited amount of data was collected in the morning at the pedestrian and school signal locations when only the school signal was activated. A 4x2 (signal operation x crosswalk location) analysis of variance was calculated for vehicle speeds. There was no significant interaction. The mean speeds for signal operation are shown below:

	Mean Speed at Each Location (mi/h)	
Signal Operation	Pedestrian Signal	School Signal
None	32.9	35.3
Pedestrian Signal Only	31.8	35.4
School Signal Only	30.1	32.5
Both Pedestrian & School Signals	28.2	30.6

Data were also collected to determine the effect of the presence of pedestrians on vehicle speeds. As previously mentioned, there was not much pedestrian traffic at the crosswalk locations so a member of the research team posed as a pedestrian in the vicinity of each crosswalk. Vehicle speeds were significantly lower (34.2 mi/h) when a pedestrian was present than when no pedestrian was present (34.8 mi/h). This difference persisted regardless of crosswalk location or operation of the pedestrian signal.

Conclusions

An analysis of driver behavior indicated that the special pedestrian crossing signal has no significant effect on vehicle mean speeds. Although a very slight (0.7 mi/h) speed reduction was produced by the special pedestrian signal, a larger and significant (4.5 mi/h) reduction resulted when the special pedestrian signal was operating at the same time as a nearby school crossing signal. The school crossing signal alone produced a 2.8 mi/h reduction in vehicle speeds that was not found to be statistically significant. What is not known is whether these relatively small and frequently statistically not significant speed reductions are indicative of a change in the driver's attitude or perceptual "set" that may result in a safer pedestrian environment.

CASE STUDY: JERMANTOWN ROAD, FAIRFAX, VIRGINIA

Summary

This case study evaluated a unique pedestrian signal located at the intersection of Jermantown Road and Orchard Street. The signal consists of a three head traffic signal, which is activated for a 3-hour period in the afternoon. The top and bottom signal heads contain yellow lights that flash alternately. The middle signal head contains a red "X." One pedestrian signal is placed on each approach to Orchard Street. To determine the effect of the activated signal, vehicle speed data were recorded at the intersection and at an adjacent intersection. Pedestrian counts and crossing locations were also recorded.

Background

Jermantown Road runs northeast-southwest through Fairfax City, Virginia. At the study site, Jermantown Road is a two-lane roadway. The pedestrian signal was installed after the installation of a similar signal on Old Lee Highway.

Housing developments exist on both sides of the roadway at the site. Jermantown Elementary School is located on Jermantown Road approximately 500 feet north of Orchard Street.

As a control, vehicle and pedestrian data were also collected at Carol Street, located about 1500 feet northeast of Orchard Street.

Study Objective

The objective of the case study was to determine the effect of the pedestrian signal on vehicle operations, measured in terms of vehicle speed and pedestrian behavior. Specifically, the study was designed to determine the following:

- Difference in vehicle speeds at the two crosswalks when the pedestrian signal is operating and not operating.
- Pedestrian looking behavior.
- Pedestrian crossing location.

- Numbers and ages of pedestrians crossing Jermantown Road.

Data Collection

The following data were collected during August 1985 at each of the two crosswalks for vehicles traveling in both directions on Jermantown Road:

- Free flow vehicle speed when the pedestrian signal was operating and not operating. Vehicle speeds were measured at both crosswalks.
- Presence of pedestrians for each vehicle speed measured.
- Numbers of pedestrians crossing Jermantown Road.

Results

On the first day of data collection, only 10 pedestrians were observed crossing Jermantown Road within the study site. Therefore, on the second day of data collection, one member of the data collection team occasionally crossed Jermantown Road to obtain vehicle speed data when a pedestrian was present. Because so few pedestrians were observed, no pedestrian behavioral data are reported. The vehicle speed data were analyzed in terms of whether a pedestrian (actual or member of the team) was present.

Initially, all of the data were analyzed using a 2x2 (crosswalk location x signal operation) analysis of variance. Mean vehicle speeds were significantly lower at Orchard Street (34.1 mi/h) than at Carol Street (35.6 mi/h) ($F[1,577]=17.22$, $p<0.001$). However, there was a significant interaction between the crosswalk location and the operation of the signal ($F[1,577]=38.98$, $p<0.001$). As shown below, when the pedestrian signal was operating, speeds at Orchard were significantly lower than the speeds at Carol. However, when the pedestrian signal was not operating, there was no significant difference between the speeds at Orchard and at Carol.

The most important aspect of the study involved the mean vehicle speeds at Orchard Street when the signal was on and when it was off. To more easily interpret the results, the data were analyzed separately for Orchard Street and then for Carol Street, the control site. A 2x2x2 (date x direction x signal operation) analysis of variance and a 2x2x2 (direction x signal operation x presence of pedestrians) analysis of variance were calculated for each site.

As indicated in the table below, there was a significant difference in vehicle speeds at Orchard Street when the signal was operating ($F[1,335] = 23.35$, $p<0.001$). However, there was also a significant difference in mean vehicle speeds on August 7 as opposed to August 14 ($F[1,335]=8.00$, $p<0.005$). The data are shown below. There was no significant difference in mean vehicle speeds when a pedestrian was present as opposed to not present or between northbound vehicles as opposed to southbound vehicles.

	Mean Vehicle Speed (mi/h)	
Signal Operation	Orchard Street (Signal)	Carol Street (No Signal)
On	32.5	36.6
Off	35.2	34.7
Date		
August 7	35.0	34.7
August 14	33.0	36.6

There was no significant interaction between any two of the variables, indicating that vehicle speeds were lower when the signal was on regardless of date, vehicle direction of travel, or presence of pedestrians. This also indicates vehicle speeds at Orchard Street were higher on August 7 regardless of signal operation, vehicle direction of travel, or presence of pedestrians.

At Carol Street, about 1,500 feet northeast of the signal, there was a significant difference in mean vehicle speeds when the signal was operating as opposed to not operating ($F[1,230]=13.10$, $p<0.001$) and there was a significant difference by date ($F[1,230]=13.86$, $p<0.001$). There was no significant difference in vehicle speeds when pedestrians were present as opposed to not present, or for northbound vehicles as opposed to southbound vehicles. As shown above, the vehicle speeds at Carol Street were higher when the pedestrian signal was on as opposed to off. Also, higher speeds occurred on August 14, whereas at Orchard Street, the higher speeds occurred on August 7.

Again there was no significant interaction between any two of the variables. This means that vehicle speeds were higher when the signal was on regardless of date, vehicle direction of travel, or presence of pedestrians. This also means that vehicle speeds at Carol Street were higher on August 14 regardless of signal operation, vehicle direction of travel, or presence of pedestrians.

Summary

The analysis showed that vehicle speeds were significantly lower at Orchard Street (the experimental site) when the signal was operating than when it was not operating. However, at Carol Street (the control site) vehicle speeds were significantly higher when the signal was operating. This may indicate that while drivers slow down at Orchard Street when the signal is on, they drive faster at Carol Street to compensate. If this were true, one would expect a difference in vehicle speeds by direction of travel at Carol Street; such was not the case. The results of this case study are not clear. Apparently a flashing pedestrian signal can slow traffic in some situations, but possible negative effects (i.e., increased speeds at neighboring locations) are not completely understood.

CASE STUDY: HAMILTON TOWNSHIP HIGH SCHOOL WEST, NEW JERSEY

Background

Hamilton Township is a suburb of Trenton, New Jersey. Principally a residential community, Hamilton Township is served by two senior high schools. The west school or Hamilton West, as it is known, has a 1,409-member student body.

The school buildings and athletic fields are separated by a two-lane collector street (48-foot width curb-to-curb), called Park Avenue. Faculty, student, and special event parking areas are located adjacent to the school buildings and are also separated from the athletic fields by Park Avenue. The principal crossing to the fields from the school property is a midblock crosswalk located 400 feet from the nearest four-way intersection. The four-way intersection is signalized. During periods of warm weather, physical education classes are held outdoors. There are seven physical education periods that generate a total of 14 crossings per day. Approximately 125 to 150 students cross the road during each of the 14 group crossings. On days when there are special events, event participants and spectators must cross Park Avenue to get to the fields from the parking lot.

The traffic control devices (TCDs) used at the location were a 9-1/2-foot wide ladder-type crosswalk marking and two School Crossing Signs (S2-1), placed one for each direction of traffic. On special event days, special police were hired to handle the vehicular and pedestrian traffic.

Although they had been requested by school officials only 1 year earlier, the existing TCDs were not adequate to handle the situation described, in the opinion of school officials. The Superintendent of Schools wrote to the township police to express his concern and suggest that pedestrian actuated flashing Pedestrian Crossing Signs (W11-2A) be installed to replace the existing signing. The request was passed on to the New Jersey Department of Transportation for approval. The special devices were approved and installed in September 1984.

The devices consist of a 30-by-30-inch Pedestrian Crossing Sign (W11-2A) and two 8-inch yellow signals (figure 10). The signals alternately flash at a rate of 50 to 60 flashes per minute. The flashers are activated by a push button on the side of the pole opposite the sign (figure 11). This allows the pedestrian to push the button and activate the signal just before stepping into the crosswalk. A pilot light is also included on the rear of the device (figure 11). This light tells the pedestrian if the device is working properly. If the pilot light goes on when the button is pushed, the signals are flashing. If the pilot light does not go on, the signals are out. The device is controlled by a key switch which supplies power to the device only during school hours or special events.

Data Collection and Analysis

A spot speed analysis was conducted at the site to see if the device had any effect on the prevailing speed condition, with the intent to conduct speed observations for four conditions: (1) device activated, pedestrians present; (2) device dark, no pedestrians present; (3) device activated, no pedestrians present; and (4) device dark, pedestrians present. Since the speed observations were made on a day when no physical education classes were held, it was not possible to make observations for conditions 1 and 4. Conditions 1 and 4 were considered significant because some research studies have shown that motorists' speeds near school areas are altered from their normal speed only when they can see school children near the crossing areas (Reiss & Robertson, 1976). The posted speed limit in the area is 25 mi/h.

The results of the speed analysis show that for condition 2, the mean travel speed was 29.8 mi/h. The standard deviation was 4.6. The 85th percentile speed fell between 32 and 33 mi/h. For condition 3, the mean travel speed was 28.8 mi/h. The standard deviation was 3.8 and the 85th percentile speed fell between 32 and 33 mi/h.

A t-test was performed on the mean speeds for the two conditions and the results showed that there was no significant difference between the means.

Figure 10. Pedestrian crossing sign and flashing signal.

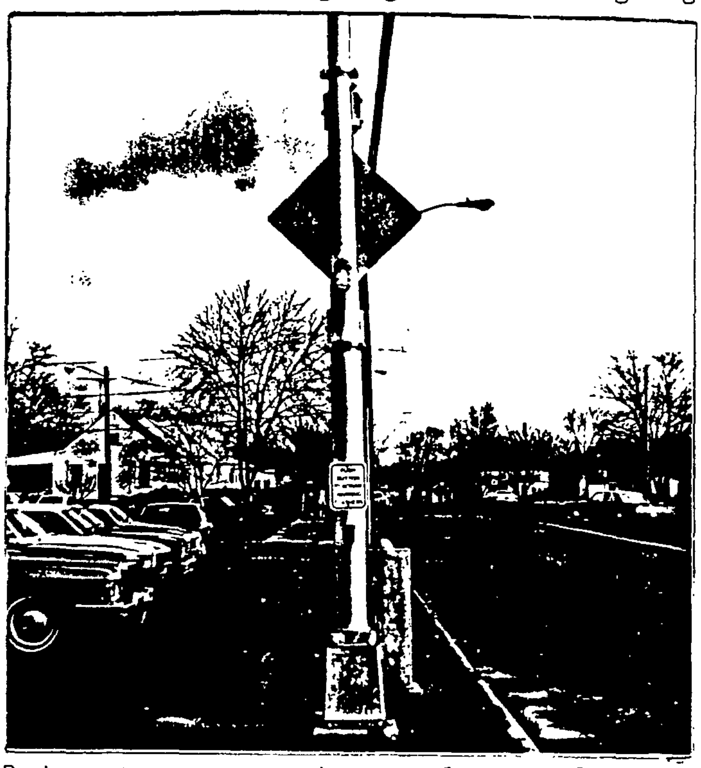


Figure 11. Pedestrian-activated control and pilot light.

Given the conclusions of the two previous case studies and the results here, which showed no real difference in motorist behavior, it was necessary to make a second trip to the site to observe conditions when pedestrians were present. During the second trip to the site, an attempt was made to conduct speed observations for the previously mentioned four conditions. Again there was some problem in obtaining data for condition 4. Field personnel did not feel it was in the best interest of the students or themselves, considering potential liability situations, to ask the students to cross or be near the crosswalk if the device was not activated. In practice, physical education students do cross to the fields without activating the device; however, this occurrence was not frequent enough to enable the data collectors to record a statistically significant number of observations.

The results of the second speed analysis show for condition 1, the mean travel speed was 28.5 mi/h. The standard deviation was 4.8. The 85th percentile speed fell between 33 and 34 mi/h. For condition 2, the mean travel speed was 29.2 mi/h, and the deviation was 4.1. The 85th percentile speed fell between 32 and 33 mi/h. For condition 3, the mean travel speed was 31.8 mi/h. The standard deviation was 3.7, and the 85th percentile speed fell between 33 and 34 mi/h.

An analysis of variance showed a significant difference between the mean speeds for conditions 1, 2, and 3 ($F[2,87]=5.08$, $p<.005$). A Newman-Keuls post hoc test revealed that conditions 1 and 2 were equivalent, but both were different from condition 3. While these differences between the conditions exist, they are difficult to explain. It is odd that no difference exists between conditions 1 and 2 when the device is in a fully operational mode (1), and when it is not in use (2). However, there is a difference between the mean speeds when the device is flashing and when it is dark, and the speeds increase when the device is flashing.

There was an observed difference in motorist behavior for the condition 2 observations. If the device was activated, it could be seen before the pedestrians were visible. Once the motorists could see the device, they were in range of the radar used for taking the speed observations. The initial speed recorded was the one used for analysis purposes and reported above. However, once the motorists could see the large group of pedestrians crossing or waiting to cross the streets, their travel speeds dropped radically and often they would come to a complete stop. Again this was only when they could see a large group of pedestrians. With the device flashing and a group of students waiting to cross, many motorists did not slow up at all and continued by the school at their normal free flow speed.

Conclusions

When the device is operating and there are pedestrians present, there is some modification of behavior of speed by some motorists. How much of this effect is caused by the device and how much is caused by the presence of the students? Based on the results of the spot speed check and other research (Reiss & Robertson, 1976), it would appear that the presence of pedestrians causes the small degree of driver behavior modification. It appears that in most situations, the pedestrians and motorists were sizing up the situation and acting in what each felt was an appropriate manner. Most often they seemed oblivious to the device.

It appears that a device such as the one used at Hamilton West High School is of negligible value. While conducting the study, a member of the data collection team had the opportunity to speak with local police and school officials. Their feelings were that the device did not do what they had originally hoped it would, i.e., slow the traffic on Park Avenue.

CASE STUDY: EDMONDSON AVENUE, BALTIMORE, MARYLAND

Background

Edmondson Avenue is a major arterial running east-west through Baltimore City. It is designated U.S. Route 40. In 1984, a 2-mile section between Hilton and Cooks Avenues on the west side of Baltimore was upgraded through repaving, left-turn channelization, and the installation of pedestrian crosswalks.

Edmondson Avenue is a six-lane roadway; the outer lanes are used for parallel parking during the off-peak hours. Parking is restricted inbound during the morning peak and outbound during the afternoon peak. Generally, the section of Edmondson Avenue between Hilton Avenue and the shopping center is characterized by low-income rowhouses with some commercial establishments, primarily on street corners. The section between the shopping center and Cooks Avenue is generally characterized by single family residences with some commercial establishments.

Since a before-after analysis of the improvements implemented in 1984 was not possible, North Avenue was selected as a control site. North Avenue is similar to Edmondson Avenue in that it is generally characterized by low-income rowhouses with some commercial establishments. It is also a major arterial running east-west through Baltimore City. A 2-mile segment of North Avenue was selected between Charles Street and Gay Street. It also consists of six lanes of traffic with the outside lanes used for parking. Narrow concrete medians are in place throughout most of the 2-mile segment.

Characteristics of the intersections located on the study sections on Edmondson and North Avenues are shown in the following chart. In terms of the characteristics listed, Edmondson and North are quite similar. North has somewhat more intersections and therefore somewhat shorter block lengths. The biggest difference is in left-turn lanes. Since adding left-turn channelization was one of the improvements made to Edmondson, not surprisingly all but one of the intersection legs had left-turn channelization.

Characteristic	Experimental: Edmondson	Control: North
Length	2 miles	2 miles
Number of Intersections	26	36
Percentage Signalized Intersections	42%	38%
Percentage of Signalized Intersections With Pedestrian Signal	100%	100%
Percentage of Intersection Legs That Are Two-Way	40%	40%
Percentage of Intersection Legs That Have Pedestrian Markings	35%	42%
Percentage of Intersection Legs That Have Left-Turn Lanes (Where Possible)	97%	28%

Study Objectives

The case study had two major objectives. First, pedestrian accidents were analyzed on Edmondson Avenue before and after the improvements with North Avenue used as a control site. Second, vehicle and pedestrian observations were conducted to determine what effect the improvements may have had on vehicle and pedestrian behavior.

Accident Study

Approximately 1,800 pedestrian accidents occur each year, of which 25 to 30 are fatalities. Citywide there are about 65 motor vehicle fatalities each year. To determine if the improvements implemented affected pedestrian safety, motor vehicle accidents from 1982 to 1985 were analyzed for the study sections on Edmondson and North Avenues. Since the improvements were started in March, 1984 and completed on January 2, 1985, 1982 and 1983 are considered "before," 1984 is considered "during," and 1985 is "after."

The number of pedestrian and motor vehicle accidents that occurred each year on North and Edmondson Avenues follows.

	1982 (Before)	1983 (Before)	1984 (During)	1985 (After)
Number of Pedestrian Accidents				
Edmondson (Experimental)	27	31	30	18
North (Control)	23	34	34	35
Number of Motor Vehicle Accidents				
Edmondson (Experimental)	481	532	481	479
North (Control)	510	493	514	552

Although the total number of motor vehicle accidents has been relatively stable over the years on both streets, there was a 40 percent reduction in pedestrian accidents (30 to 18) on North Avenue after the improvements. This change is significant at the 0.05 level if a simple before-after evaluation design is used. However, when North Avenue is used as the control, the resulting chi-square is not significant (0.21).

Behavioral Observations

Pedestrian and vehicle behavioral data were collected and analyzed to determine if there were any behavioral differences between the experimental (Edmondson) and the control (North) locations. In addition, data collection locations were selected to permit comparisons between high accident and low/moderate accident locations. Three intersections on North Avenue and three intersections on Edmondson Avenue were selected for the collection of vehicle and pedestrian activity data. Each of the six intersections is signalized.

Observations were made during 4 weekdays in August, 1985 by two data collectors. One data collector observed pedestrian activity on each of the four legs of the intersection and recorded various pedestrian behaviors. Pedestrian behaviors that were observed included: crossing location (relative to crosswalk), looking behavior (before and/or during crossing), and crossing behavior (with/against light, running). The other data collector counted the number of turning vehicles (by direction and location), as well as the through traffic on each cross street. Through traffic on North and Edmondson was not counted because 24-hour traffic volume counts were obtained from the Baltimore City Department of Transit and Traffic.

A rotating data collection schedule was used. Observations were made at each intersection for about 15 minutes and the observers moved to the next intersection. Thus, data were collected at each intersection at least once every 2 hours on each of the 4 days of data collection. This rotating sampling counting procedure was used to minimize the effects of the day-to- day variability in pedestrian activity levels (i.e., counting site 1 on Monday, site 2 on Tuesday, etc.). The number of pedestrians counted was used to project an average number of pedestrians per hour for each site. The pedestrian volume and vehicle volume figures for the three intersections on North and the three intersections on Edmondson are shown in table 1.

The intersections are listed in order of increasing number of pedestrian accidents (columns 1 and 2). The pedestrian volumes shown (column 3) indicate that the intersections on North were much busier than those on Edmondson. Accident rates were computed by dividing the mean number of accidents per year (row 2) by the number of pedestrians per year (column 3). This arbitrary "rate" figure indicates the relative safety of each intersection in terms of pedestrian exposure. The highest rates (0.43) were found at the high (Allendale) and the low/moderate (Athol) accident sites on Edmondson. All of the sites on North were safer than any of the sites on Edmondson. This is a function of North Avenue intersections having twice the pedestrian activity as the Edmondson Avenue intersections for comparable accident rates. The "safest" site was Aisquith at North, which had an accident rate three-and-a-half times less (0.12) than the more dangerous sites on Edmondson (0.43).

The Average Daily Traffic (ADT) figures provided by the Baltimore City Department of Transit and Traffic were used to project an approximate annual traffic volume (row 5). North Avenue had much less traffic than did Edmondson. A pedestrian accident rate based on the vehicle volume (row 6) was computed by dividing the number of accidents annually by the annual vehicle volume. The accident rates at five of the six sites fell within the relatively small range of 0.11 to 0.23. The intersection at North and Greenmont had the highest accident rate at 0.72.

Table 1. Pedestrian and vehicle volumes and accident rates at six intersections in Baltimore.

	Edmondson			North		
	Athol	Edgewood	Allendale	Hartford	Aisquith	Greenmont
1) Number of Pedestrian Accidents (1982-1985)	7	9	16	6	8	24
2) Pedestrian Accidents Per Year (Average)	1.75	2.25	4.00	1.50	2.00	6.00
3) Pedestrians Per Year[a] (PPY x 10^5)	4.0	6.3	9.3	7.1	17.2	22.2
4) PPY Accident Rate (2) ÷ (3)	0.43	0.36	0.43	0.21	0.12	0.27
5) Vehicles Per Year[b] (VPY x 10^6)	16.2	17.6	17.6	8.3	12.3	8.3
6) VPY Accident Rate (2) ÷ (5)	0.11	0.13	0.23	0.18	0.16	0.72
7) PxV Exposure (3) x (5) x	64.8	110.9	163.7	58.9	211.6	184.3
8) PxV Accident Rate (2) ÷ (7) x 10^2	2.7	2.0	2.4	2.5	0.9	3.3
9) Mean PxV Accident Rate - All Sites		2.36			2.23	

[a]Projections based on average hourly pedestrian volume counted x 365 days x 16 hours.

[b]Projections based on total 24-hour volumes x 365 days.

Both the pedestrian-volume-based accident rate and the vehicle-volume-based accident rate provided an exposure-based indication of the hazard associated with each intersection. Edmondson was somewhat more hazardous in terms of pedestrian exposure but was somewhat safer in terms of vehicular exposure. A third denominator for exposure-based analyses can be based on the product of the pedestrian volumes (P) and the vehicle volumes (V). The PxV exposure at each intersection is shown in row 7. The accident rate based on the PxV exposure is shown in row 8. The intersections on Edmondson showed remarkably similar accident rates. Unknown factors (i.e., not the high PxV exposure) were responsible for the high accident frequency at Allendale. The intersections on North were not quite as comparable in their PxV-based accident rates. North and Aisquith, partly because of its higher vehicle volumes, was the safest intersection in terms of PxV exposure. The intersection with the largest number of accidents (Greenmont) coincidentally had the highest PxV accident rate. The average accident rates for the intersections on North and the intersections on Edmondson are shown in row 9. The bottom line indicates that there were no meaningful differences, in terms of PxV exposure, between Edmondson Avenue and North Avenue.

Even though there were apparently no major differences between North and Edmondson in terms of PxV exposure or accident rate, an analysis of the detailed pedestrian behavioral data was undertaken. This was done to see if there were any commonalities and/or differences between the experimental and control sites <u>and</u> to see if certain factors (such as specific pedestrian characteristics or specific pedestrian behaviors) were associated with high accident locations at either site.

Tabulations were made of the following observed pedestrian characteristics and pedestrian behaviors: pedestrian age, pedestrian sex, crossing location, crossing behavior, signal compliance, and looking behavior.

The sex distributions of the pedestrians observed at each intersection are shown in the following chart.

Intersection	Mean Number of Accidents	Pedestrian Sex (Percent) Male	Female
Edmondson & Athol/Wood	1.75	53.9	46.1
Edmondson & Edgewood	2.25	62.8	37.2
Edmondson & Allendale	4.00	53.8	46.2
North & Hartford	1.50	48.5	51.5
North & Aisquith	2.00	70.8	29.2
North & Greenmont	6.00	56.5	43.5

Although North Avenue appeared to be somewhat more variable, the percentage of male pedestrians on Edmondson (56.8) was essentially the same as that on North (58.6). There did not appear to be any relationship between sex and number of accidents.

The age distribution of the pedestrians observed is shown below. It is apparent that there were many more younger pedestrians on Edmondson (13.1 percent at all three sites were 12 or younger) than on North (only 6.2 percent were 12 or younger).

Intersection	Mean # of Acc.	Pedestrian Age Category (Percent) 1-6	7-12	13-19	20-25	26-30	31-40	41-50	51-60	61-70
Edmondson & Athol	1.75	2.3	7.5	16.4	32.2	13.7	10.8	10.3	5.1	1.7
Edmondson & Edgewood	2.25	7.3	7.1	15.6	32.4	9.4	8.6	15.5	3.1	1.2
Edmondson & Allendale	4.10	5.2	9.8	15.8	25.1	12.7	14.7	11.6	4.2	0.9
North & Hartford	1.50	2.7	4.6	10.8	31.2	8.7	15.6	19.0	5.6	1.7
North & Aisquith	2.00	1.6	1.8	7.2	39.2	7.0	17.4	19.6	5.8	0.4
North & Greenmont	6.00	2.8	5.2	11.7	25.7	13.7	19.1	15.4	4.3	2.1

The data collection team also categorized each pedestrian observed by crossing location. Crossing location was divided into five specific categories:

- In Crosswalk - pedestrian crossed road entirely in crosswalk.
- Late Entry - pedestrian took two or more steps outside of crosswalk area, then entered crosswalk.
- Early Exit - pedestrian began crossing within crosswalk, then took two or more steps outside of crosswalk area.
- Jaywalk - pedestrian crossed outside of crosswalk area, but within 50 feet of crosswalk.
- Midblock - pedestrian crossed more than 50 feet from crosswalk.

The percentage of pedestrians observed in each category by intersection is shown below.

Intersection	Mean # of Accidents	Pedestrian Crossing Behavior (Percent) In Crosswalk	Late Entry	Early Exit	Jaywalk	Midblock
Edmondson & Athol/Wood	1.75	55.2	1.3	2.5	15.3	25.7
Edmondson & Edgewood	2.25	61.6	3.4	5.5	13.8	15.9
Edmondson & Allendale	4.00	49.4	5.9	6.3	29.2	9.2
North & Hartford	1.50	61.6	1.4	7.4	22.1	7.5
North & Aisquith	2.00	46.5	1.6	8.6	18.6	24.7
North & Greenmont	6.00	66.5	5.8	9.5	12.7	5.5

There were no major differences in the crossing behavior exhibited by pedestrians at Edmondson or by those at North. The biggest differences appeared to be related to the mean number of accidents occurring at each intersection. Many of the effects, however, were not consistent between Edmondson and North. The intersection with the highest percentage of in-crosswalk crossings was North and Greenmont, which also had the highest number of accidents. The high accident intersection on Edmondson (Allenwood) had the next to the lowest percentage of in-crosswalk crossings. That same intersection had the highest occurrence of jaywalking. Both high accident locations had relatively low percentages of midblock crossings, which is surprising since midblock crossings are frequently involved in accidents. Therefore, pedestrian crossing location does not appear to be highly correlated with accident frequency.

It had been hypothesized that crossing location might vary by intersection leg. Due to the width of Edmondson and North Avenues one might have expected pedestrians to behave differently when crossing the east-west (wider) legs versus the north-south legs of the intersecting roadways. However, an analysis of the data by intersection leg revealed no consistent pattern of crossing location for pedestrians crossing the east-west legs versus the north-south legs.

In addition to pedestrian crossing location, data were also collected on pedestrian crossing speed. Previous pedestrian accident research has shown that pedestrians often are running when struck by a vehicle. The percentage of pedestrians who ran across the intersection is shown below.

Intersection	Mean # of Ped Accidents	Percent of Pedestrians Running Across Intersection
Edmondson & Athol/Wood	1.75	19.2
Edmondson & Edgewood	2.25	15.6
Edmondson & Allendale	4.00	13.3
North & Hartford	1.50	11.5
North & Aisquith	2.00	10.0
North & Greenmont	6.00	12.3

No consistent trends are evident, but running was not more common at the high accident locations as was hypothesized. Edmondson Avenue did show consistently more running behavior. This could have been a function of either the younger pedestrians or the higher traffic volumes and wider roadway found on Edmondson or a combination of both. Analyzing the data by intersection leg revealed that for five of the six intersections, the higher percentage of pedestrians ran across the east-west legs, i.e., across Edmondson and North Avenue. For North and Hartford, 21.9 percent ran across the east leg, 5.5 percent across the west leg, 4.2 percent across the south leg, and 13.4 percent across the north leg. Also, for Edmondson and Athol/Woodridge (which had the highest overall percentage of pedestrians running), the analysis by intersection leg was interesting. For the north and south legs, 8.1 percent and 11.1 percent, respectively, of the pedestrians ran; while for the east and west legs, an extremely high percent, 50.8 and 23.5, respectively, of the pedestrians ran.

The percentage of pedestrians by intersection who were trapped on the median is shown below. Being trapped on the median occurs when a pedestrian crosses to the median, at which point the pedestrian signal changes to a steady DON'T WALK and/or the traffic signal for the corresponding traffic movement changes to red.

Intersection	Mean # of Ped Accidents	Percent of Pedestrians Trapped on the Median
Edmondson & Athol/Wood	1.75	13.7
Edmondson & Edgewood	2.25	26.7
Edmondson & Allendale	4.00	14.8
North & Hartford	1.50	12.5
North & Aisquith	2.00	3.8
North & Greenmont	6.00	10.7

There was no relationship between number of accidents and pedestrians being trapped on the median. Edmondson Avenue clearly had more pedestrians trapped on the median. It is not known if this was a result of the improvements made or the higher traffic volumes on Edmondson.

Data were also collected on the compliance shown by pedestrians to the traffic signals. While the majority of pedestrian signals at the six intersections have push buttons, some automatically change to WALK when the corresponding traffic signal changes to green. Other pedestrian signals do not change unless the pedestrian pushes the button. Thus, three levels of signal compliance were recorded:

- Against Signal, Against Light - pedestrian begins to cross when the traffic signal displays red and the pedestrian signal displays a steady DON'T WALK.
- Against Signal, With Light - pedestrian begins to cross when the traffic signal displays green, but the pedestrian signal displays a steady DON'T WALK because the pedestrian did not push the button. Or, pedestrian begins to cross when the traffic signal displays green, but the pedestrian signal displays a flashing DON'T WALK.
- With Signal, With Light - pedestrian begins to cross when the traffic signal displays green and the pedestrian signal displays WALK either because the pedestrian signal automatically changed or because the pedestrian pushed the button.

The analysis of signal compliance was further confounded by the fact that only two of the eight possible pedestrian movements are provided a pedestrian signal at North and Aisquith. The two pedestrian signals are located on the northeast and northwest corners of the intersection and face south, thus serving northbound pedestrians only. Two additional levels of signal compliance were recorded for North and Aisquith: No pedestrian signal, against light; and no pedestrian signal, with light.

The percentages of pedestrians observed by intersection and signal compliance are shown in the following chart.

Intersection	Average # of Ped Accidents Per Year	Percent of Pedestrian Crossing: Against Signal Against Light	Against Signal With Light	With Signal With Light
Edmondson & Athol/Wood	1.75	34.3	25.5	40.2
Edmondson & Edgewood	2.25	44.0	9.6	46.4
Edmondson & Allendale	4.00	27.4	28.8	43.8
North & Hartford	1.50	35.7	4.7	59.5
North & Aisquith*	2.00	41.7	2.4	55.9
North & Greenmont	6.00	43.4	36.5	20.1

*NOTE: For North & Aisquith, percentages with No Pedestrian Signal are combined with other designations as follows: "Against Light" is combined with "Against Signal Against Light" and "With Light" is combined with "With Signal With Light."

There does not appear to be a relationship between total noncompliance (against pedestrian signal, against traffic light) and the number of accidents at the location. The relatively large number of pedestrians (36.5%) at the highest accident location (North and Greenmont) crossing with the traffic light but against the pedestrian signal suggests that pedestrian signal timing and/or activation at that location may need modification.

An analysis of the data by intersection leg revealed that for four of the six intersections the east and west legs had a higher percentage of noncompliance than did the north and south legs. Why the larger, busier road had the higher noncompliance rate is not known. It could be simply because the east-west roads have longer through cycles and thus present longer opportunities for the pedestrian to cross "against the light."

The final pedestrian behavior that was observed was pedestrian looking behavior. The data collectors recorded whether each pedestrian did not look for approaching vehicles, looked for approaching vehicles only before crossing, looked during the crossing, or looked both before and during the crossing. The percentages of pedestrians observed by intersection and looking behavior are shown below:

Intersection	Mean # of Ped Accidents	Did Not Look	Looked Before Only	Looked During Only	Looked Before & During
Edmondson & Athol/Wood	1.75	4.8	24.3	1.0	68.7
Edmondson & Edgewood	2.25	11.3	17.0	2.0	69.3
Edmondson & Allendale	4.00	12.1	25.8	0.6	57.6
North & Hartford	1.50	2.1	14.4	0.0	83.1
North & Aisquith	2.00	2.4	19.8	0.0	77.8
North & Greenmont	6.00	3.1	15.2	0.0	81.0

As would be expected, few pedestrians looked during if they did not look before. The higher percentages of pedestrians who did not look at all were found on Edmondson and Allendale, and Edmondson and Edgewood. It is interesting to note that three intersections on Edmondson (the study site) had lower percentages of pedestrians who looked before and during than did the intersections on North (the control site).

More pedestrians did not look for oncoming traffic at the three intersections on Edmondson (average percentage of pedestrians who did not look = 9.4%) than the intersections on North (average percentage of pedestrians who did not look = 2.5%). Although the high accident locations on both North and Edmondson also had the highest percentage of pedestrians who did not look, the correlation between looking behavior and accident frequency was not significant. The high accident location on Edmondson had the lowest percentage of pedestrians who looked both before and during their crossing (57.6%). However, the high accident location on North had one of the highest percentages of pedestrians who looked both before and during their crossing (81.0%).

An analysis of the data by intersection leg revealed that five of the six intersections had higher percentages of pedestrians who looked before and during on the east and west legs, while higher percentages of pedestrians who only looked before were found on the north and south legs. This is probably related to the width of Edmondson and North, the overall higher vehicle volumes, and the likelihood that a pedestrian could not complete a crossing without looking during the time allotted by the signal phasing.

CHAPTER IV
IMPROVEMENTS TO LOCAL STREETS

INTRODUCTION

This chapter describes the activities undertaken in Task C, the investigation of engineering improvements to local streets for pedestrian safety. Three major activities were carried out to achieve the objectives of this task:

- Analysis of pedestrian exposure data.
- State-of-the-practice review.
- Case studies of local street improvements.

The exposure data analysis was carried out to identify the characteristics of local streets that were hazardous to pedestrians as well as those characteristics that were conducive to a safe pedestrian environment.

The state-of-the-practice review involved contacting nine local officials to determine the kinds of improvements that are currently being used by local practitioners to provide for a safe pedestrian environment on local streets. In conducting this state-of-the-practice review, local individuals were contacted to determine their attitudes towards such techniques as chokers, speed bumps, diverters, traffic control plans; certain street modifications such as woonerfs; and other techniques that are thought to improve the pedestrian environment.

The final activity in the task involved conducting several case studies of existing engineering improvements that were installed on local streets to improve the pedestrian environment. Three case study evaluations were conducted. These included:

- Arlington, Virginia - Lyon Village.
- Clark County, Nevada - Royal Crest Rancheros.
- Berkeley, California - Traffic Diverter Project.

ANALYSIS OF PEDESTRIAN EXPOSURE DATA ON LOCAL STREETS

Local streets were selected for further study because they have a PxV hazard score of +1.6. This means that while local streets have 24.0 percent of the pedestrian (P) and vehicle (V) exposure, 39.4 percent of pedestrian accidents occur on these types of streets.

All of the variables contained in the exposure data base were analyzed for local streets. Some of the variables were determined merely to describe typical characteristics of local streets. For example, most local streets have two lanes so that an analysis of local streets by number of lanes did not produce two comparison groups. This condition was true for the following characteristics:

- Number of Lanes - Two or less.
- Medians - None.
- Lane Markings - None.
- Channelization - None.
- Parking Meters - None.
- Commercial Lighting - None.

A discussion of the remaining variables relevant to local streets follows.

Land Use

In terms of the pedestrian hazard scores, all land use types were neither safe nor hazardous, i.e., the percentage of pedestrian exposure was proportional to the percentage of accidents for each land use type. However, in terms of the PxV hazard scores, 100 percent residential areas were more hazardous and commercial/industrial areas were safer. Mixed residential areas were neither more hazardous nor safer than other areas.

Land Use at Intersection	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
100% Residential	42.2	62.4	38.3	22.2	-1.5	+1.1	+1.9
Commercial/Industrial	16.0	7.8	21.4	34.3	+2.0	-1.3	-2.1
Mixed Residential	41.8	29.8	40.3	43.5	+1.4	+1.0	-1.0

Length of Block

One might expect that locations with longer blocks, and thus greater distances between intersections, would have more accidents because pedestrians are more apt to cross midblock to avoid the longer walk to the nearest intersection. The hazard scores for local streets, as well as for all functional classifications, suggested this is not the case. Accidents occurred at blocks of various lengths in nearly the same distribution as the blocks occurred in the projection of sites and in nearly the same distribution of pedestrian exposure. In terms of the PxV exposure measure, shorter blocks were slightly more hazardous, blocks of moderate length were slightly safer, and long blocks were neither hazardous nor safe. Although one might expect an interaction between block length and land use (i.e., longer blocks tend to be residential), this did not appear to be the case.

Length of Block	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Less than 250 ft	30.9	35.2	23.9	21.6	-1.1	+1.3	+1.4
251 ft - 499 ft	32.9	34.2	39.7	44.3	-1.0	-1.2	-1.4
Greater than 500 ft	36.2	30.7	36.4	34.1	+1.2	-1.0	+1.1

Roadway Center Marking

Not surprisingly, the presence of roadway center markings on local streets seemed to be a function of vehicle volumes. Sites with no center markings had accidents in proportion to their pedestrian volume. However, these sites had lower vehicle volumes, so a hazardous PxV hazard score was produced. Conversely, sites with double solid lines were hazardous in terms of pedestrian exposure. But, since they have more vehicular traffic, a PxV hazard score that was neither safe nor hazardous resulted. Sites with single dashed center markings were safe in terms of both the P and the PxV exposure measures.

Roadway Center Markings	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	71.9	82.5	74.6	51.5	-1.2	-1.0	+1.4
Double Solid Line	18.0	8.5	8.6	21.5	+2.1	+2.1	-1.2
Single Dashed Line	9.1	6.9	14.5	21.8	+1.3	-1.6	-2.4

Parking Restrictions

In terms of the P hazard scores, parking restrictions on local streets did not affect pedestrian safety. However, if PxV exposure was considered, local streets where parking is prohibited on one or both sides, or where parking restrictions vary by time of day, were safe. Permitting parking on narrow streets was hazardous. Streets where parking is permitted on both sides were hazardous relative to those with parking restrictions.

Parking Restrictions	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Permitted Both Sides	54.5	56.9	46.1	30.5	-1.0	+1.2	+1.8
Prohibited One or Both Sides	16.0	8.9	20.9	36.7	+1.8	-1.3	-2.3
Width Restricts to One Side or Both Sides/Not Posted	9.0	27.1	7.0	2.8	-3.0	+1.3	+3.2
Restrictions Vary by Time of Day	20.5	7.0	25.9	30.0	+2.9	-1.3	-1.5

Parking on Premises

The parking on commercial premises variable was collected to test the hypothesis that locations with commercial establishments that have parking on their premises posed a threat to pedestrians because of increased vehicular traffic across the sidewalk area. This hypothesis was demonstrated to be false. Local streets with no POP were actually more hazardous for pedestrians in terms of the PxV exposure measure. This finding most likely correlates with the finding that of the three land use types, 100 percent residential areas are more hazardous. Local streets with some level of POP were safer for pedestrians in terms of the PxV exposure measure.

Parking on Premises (POP)	% of National Projections for Local Streets of:				Hazard Score		
	Acc.	Sites	Peds	P x V	Site	Peds	P x V
No Businesses with POP	73.7	75.7	59.9	48.2	-1.0	+1.2	+1.5
Businesses with POP	26.3	24.3	50.1	51.8	+1.1	-1.9	-2.0

Pedestrian Accommodations

Sites on local streets with no sidewalks were more hazardous for pedestrians in terms of both the P and the PxV exposure measures. Sites with sidewalks on one side were considerably less hazardous. Sites with sidewalks on both sides had pedestrian exposure and PxV exposure that were almost exactly proportional to their accidents. Sites with sidewalks had the majority of the accidents, but also had a greater percentage of both pedestrian and vehicular volumes. In terms of pedestrian exposure and in terms of PxV exposure, locations with no sidewalks or pathways are hazardous for pedestrians.

Pedestrian Accommodations	% of National Projections for Local Streets of:				Hazard Score		
	Acc.	Sites	Peds	P x V	Site	Peds	P x V
No sidewalks/pathways	16.9	34.3	12.4	2.2	-2.0	+1.4	+7.7
Sidewalk - One Side	7.5	18.9	6.0	3.7	-2.5	+1.2	+2.0
Sidewalk - Both Sides	75.7	46.7	81.6	94.1	+1.6	-1.1	-1.2

Curbs

Local streets with no curbs were hazardous in terms of both the P and the PxV exposure measures. However, these sites carried less than 10 percent of both the pedestrian and vehicular volumes. Sites with curbs on both sides carried the majority of the exposure, but also had the majority of accidents. The presence of curbs was closely correlated with the presence of sidewalks.

Curbs	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
No Curbs	8.7	21.5	5.6	3.1	-2.5	+1.6	+2.8
Curbs - One or Both Sides	91.3	78.5	94.4	97.0	+1.2	-1.0	-1.1

Street Lighting

Local streets with regularly spaced street lighting had pedestrian accidents very much in proportion to both pedestrian and pedestrian/vehicle exposure. Sites with no street lighting and sites with irregularly spaced street lighting were hazardous in terms of the PxV exposure measure. Thus, the lack of street lighting was hazardous for pedestrians. Even irregularly spaced street lighting appeared to be associated with a safer pedestrian environment in terms of the PxV hazard score.

Street Lighting	% of National Projections for Local Streets of: Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None	8.9	4.3	2.5	1.0	+2.1	+3.6	+8.9
Regularly Spaced	81.2	76.7	88.6	92.8	+1.1	-1.1	-1.1
Irregularly Spaced	10.0	18.9	8.9	6.2	-1.9	+1.1	+1.6

Pedestrian Age

In terms of their exposure, pedestrians in the 1-4, 5-9, and over 60 age groups were more likely to be involved in accidents on local streets. This distribution for local streets was not very different from the distribution of pedestrian ages at all accident locations. The only noticeable deviation was a result of an increase in the exposure of the very young pedestrian on local streets.

Pedestrian Age	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
01-04	15.7	1.4	+11.2
05-09	29.3	6.8	+4.3
10-14	15.0	13.6	+1.1
15-19	10.1	12.7	-1.3
20-29	8.0	20.9	-2.6
30-59	12.6	38.1	-3.0
60+	9.4	6.6	+1.4

Pedestrian Sex

Males and females were involved in accidents on local streets in proportion to their exposure. The distribution was similar to the one found for all types of locations.

Pedestrian Sex	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Male	56.2	62.1	-1.1
Female	43.8	37.9	+1.2

Pedestrian Accompaniment

Pedestrians traveling alone and pedestrians traveling with others were involved in accidents on local streets in proportion to their exposure. This was also found to be true on all types of roadways.

Pedestrian Accompaniment	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Alone	54.9	56.8	-1.0
With Others	45.1	43.2	+1.0

Pedestrian Mode

Running was much more hazardous than walking on local streets, as well as on all other roadway types.

Pedestrian Mode	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Walking	36.4	89.3	-2.4
Running	63.6	10.7	+5.9

Crossing Location

Crossing in a crosswalk was safer than other crossing locations on local streets. Crossing outside of, but within 50 feet of, a crosswalk was more hazardous than crossing midblock.

Crossing Location	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
Crosswalk	20.9	43.1	-2.1
Within 50 ft of Intersection	28.6	12.3	+2.3
Diagonally across Intersection	0.0	2.4	N/A
Midblock	50.4	42.4	+1.2

Signal Response

Although 82.3 percent of pedestrians crossed with the green, the high percentage of accidents (67.9%) resulted in a hazard score of -1.2. Crossing against the signal was hazardous for pedestrians on local streets. However, it was not as hazardous as crossing against the signal at locations other than local streets.

Signal Response	On Local Streets, Percentage of: Pedestrian Accidents	Pedestrians Observed	Hazard Score
With Signal: Green	67.9	82.3	-1.2
Against Signal: Red	32.1	17.7	+1.8

Accident Type

Nineteen (19) accident types were included in the exposure data base. For local streets, 11 accident types were not analyzed either because the number of pedestrian accidents or the number of pedestrians observed was too few to draw any sound statistical conclusions. Of the remaining eight accident types, five had negative hazard scores. This indicates that the behaviors associated with these five accident types on local streets were exhibited by pedestrians who were not involved in accidents more often than they were by pedestrians who were involved in accidents. These behaviors were relatively "safe." Of the five accident types, walking on the sidewalks, not crossing the roadway, had the highest safe hazard score.

	On Local Streets, Percentage of:		
Accident Type	Pedestrian Accidents	Pedestrians Observed	Hazard Score
Ped on Sidewalk - Not Crossing	3.9	30.9	-7.9
Exiting-Entering Parked Vehicles	5.1	15.6	-3.1
Intersection Crossing Walking	11.8	22.0	-1.9
Walking Along Roadway	5.8	9.1	-1.6
Midblock Crossing Walking	6.6	10.1	-1.5
Midblock Dart-Out	38.8	2.1	+18.5
Intersection Dash	8.3	1.8	+4.6
Playing in Roadway	6.8	4.4	+1.6

The remaining three accident types had positive hazard scores and thus represent hazardous behaviors. Not surprisingly, the midblock dart-out had the highest hazard score, while the intersection dash and playing in the roadway were also hazardous accident scenarios on local streets.

Summary

Some of the variables in the exposure data base merely described typical characteristics of local streets. These were:

- Number of Lanes - Two or less.
- Medians - None.
- Lane Markings - None.
- Channelization - None.
- Parking Meters - None.
- Commercial Lighting - None.

The analyses also revealed other general characteristics related to pedestrian safety on local streets:

- Local streets in 100 percent residential areas were more hazardous.
- Local streets where parking is permitted or where the roadway width restricts parking were more hazardous.
- Local streets without sidewalks were more hazardous.
- Local streets without curbs were more hazardous.
- Local streets without street lighting were more hazardous.
- Very young (less than 4 years old) pedestrians were particularly "at risk" on local streets.
- Running across local streets was more hazardous than walking.

STATE-OF-THE-PRACTICE REVIEW FOR LOCAL STREETS

To determine current practices for improving pedestrian safety on local streets, nine local practitioners were contacted. Five responses were received.

The practitioners were asked to indicate their opinions of the potential effectiveness of 14 pedestrian safety measures on local streets. The responses were averaged as follows: 1 - "Very effective," 2 - "Of limited effect," 3 - "Not effective," and 4 - "Potentially harmful." The results are shown in the following chart.

Pedestrian Safety Measure	Average Response
Woonerfs	1.0
Sidewalks or Pathways	1.2
Closing Streets to Through Traffic	1.4
Parking Restrictions	1.6
Street Lighting	1.8
Crosswalks: Signalized Intersections	2.0
Crosswalks: Unsignalized Intersections	2.4
Reduced Speed Limits	2.6
Intersection Sidewalk Extensions (Flares)	2.8
Mini-roundabouts	3.0
Midblock Sidewalk Extensions	3.2
Conversion to One-Way Streets	3.2
Pedestrian Crosswalks: Midblock	3.4
Speed Bumps or Humps	3.4

The following pedestrian safety measures were considered to be the most effective by the five respondents:

- Woonerfs.
- Sidewalks or Pathways.
- Closing Streets to Through Traffic.
- Parking Restrictions.
- Street Lighting.

Several of the pedestrian safety measures were considered to be not effective to the extent of being potentially harmful. These were:

- Mini-roundabouts.
- Conversion to One-Way Streets.
- Midblock Sidewalk Extensions.
- Speed Bumps or Humps.
- Pedestrian Crosswalks: Midblock.

The local practitioners were then asked to identify pedestrian safety measures they have used (or plan to use) to enhance pedestrian safety on local streets. Three respondents have used sidewalks or pathways. Six other safety measures received "one" vote by the five respondents:

- Street Lighting.
- Reduced Speed Limits.
- Crosswalks: Unsignalized Intersections.
- Closing Streets to Through Traffic.
- Woonerfs.
- Parking Restrictions.

Two other questions were asked of the local practitioners:

1. What specific warrants, guidelines, and/or criteria do you use to determine whether crosswalks should be installed at the following types of locations on local streets?

   Signalized Intersections with Pedestrian Signals

   Three respondents mark all of the intersections; one marks this type of intersection if there is any evidence of pedestrian use; and one considers pedestrian volumes.

   Signalized Intersections (with No Pedestrian Signals)

   Two respondents mark all of these intersections; two respondents mark these intersections if there is any evidence of pedestrian use; and one considers pedestrian volumes.

   Unsignalized Intersections

   One respondent marks no unsignalized intersections. Two respondents mark these types of intersections if they are on a school route. Two respondents mark these intersections if they are on a school route and also consider pedestrian volumes.

Midblock Locations

Three respondents have no midblock crosswalks. Two respondents mark midblock crosswalks if on a school route. (One of these also considers pedestrian volumes.)

School Crossings

All of the respondents mark crosswalks on designated school routes.

2. What specific warrants, guidelines, and/or criteria do you use to determine if traffic signals, pedestrian activated signals, or pedestrian signals should be installed on local streets?

All of the respondents use the Manual on Uniform Traffic Control Devices. Other criteria include gap analysis for children and the elderly, engineering judgment, accidents, and traffic volumes.

CASE STUDY: LYON VILLAGE, ARLINGTON COUNTY, VIRGINIA

This case study presents improvements made to Lyon Village, a residential area in Arlington, Virginia. Lyon Village is bounded by Lee Highway on the north, Veitch Street on the east, Wilson Boulevard on the south, and Kirkwood Road on the west. Lee Highway and Wilson Boulevard are major arterials connecting the western Virginia suburbs to Washington, D.C.

During the 1970s, the Lyon Village Citizen's Association addressed the problem of increasing vehicular traffic during the morning and afternoon peak hours through Lyon Village and the resulting noise, pollution, and safety problems. Retail stores located along Wilson Boulevard brought secondary traffic through Lyon Village throughout the day. Subway construction during this period raised concerns about future commercial development along the neighborhood's borders and potential increased commuter parking on its streets.

The Lyon Village Citizen's Association developed a Neighborhood Preservation Plan in 1977 (revised in 1978) that addressed traffic flow, parking, street lighting, and overall appearance. This plan was adopted, for the most part, by Arlington County and the majority of the recommended improvements were implemented in 1978.

The traffic engineering measures employed were designed to reduce the number of vehicles traveling through the area during the morning and afternoon peak hours and to reduce vehicle speeds. While there were few vehicular accidents within Lyon Village, some traffic engineering measures were also designed to reduce the potential for future accidents involving motor vehicles, pedestrians, and bicyclists. Other improvements, e.g., parking restrictions, landscaping, and street lighting, were intended to enhance the environment.

Traffic Engineering Improvements

Traffic engineering improvements were implemented primarily to discourage through traffic during the peak hours and to reduce vehicular speeds. Commuters during the morning rush hour typically entered Lyon Village at either 13th Street on the west or Highland, Danville, or Cleveland Streets on the north. Commuters would travel to Key Boulevard and continue eastward through Lyon Village. Exits generally were made by turning onto Custis Road, Veitch

Street, or Rhodes Street and then to a major arterial (Lee Highway or Wilson Boulevard). During the afternoon rush hours, commuters would travel through Lyon Village in the reverse direction.

The traffic engineering improvements implemented are listed below. Figure 12 depicts the location of each of these improvements.

1. Install "Do Not Enter" signs on 16th Street at Adams Street.

2. Install "No Left Turn" signs on northbound 13th Street at Highland and Hancock Streets.

3. Install "No Left Turn, 7-9am Weekdays" signs on northbound 13th Street at Irving, Hudson, and Herndon Streets.

4. Install "No Left Turn, 7-9am" signs on southbound Highland Street at Edgewood and Fillmore Streets.

5. Close Custis Road south of 16th and Adams Streets.

6. Install "Do Not Enter, 4-6:30pm" signs onto Key Boulevard from Veitch Street.

7. Install "4-Way Stop" signs at Highland and Edgewood Streets.

8. Install curb extending nubs at the intersection of Key Boulevard and Edgewood Street and at the intersection of Key Boulevard and Cleveland Street.

9. Realign the intersection of Jackson Street and Key Boulevard by converting it to a "T" intersection.

10. Extend curbs at the intersection of Key Boulevard and Highland Street and install "4-Way Stop" signs. Install a quarter diverter on Franklin Road at Highland and Key making it "one-way" out of the intersection. Apply similar treatment at 17th Street.

11. Close Custis Road north of Key Boulevard to Cleveland Street.

12. Extend the triangle at Franklin Road and Edgewood Street, creating a grass island, or "mini-park."

13. Move "Stop" sign from Hartford Street to 17th Street.

One purpose of the traffic engineering improvements was to reduce vehicular volumes through Lyon Village. Vehicular volume data were analyzed for 36 sites within Lyon Village for the "before" condition (April 1978) and

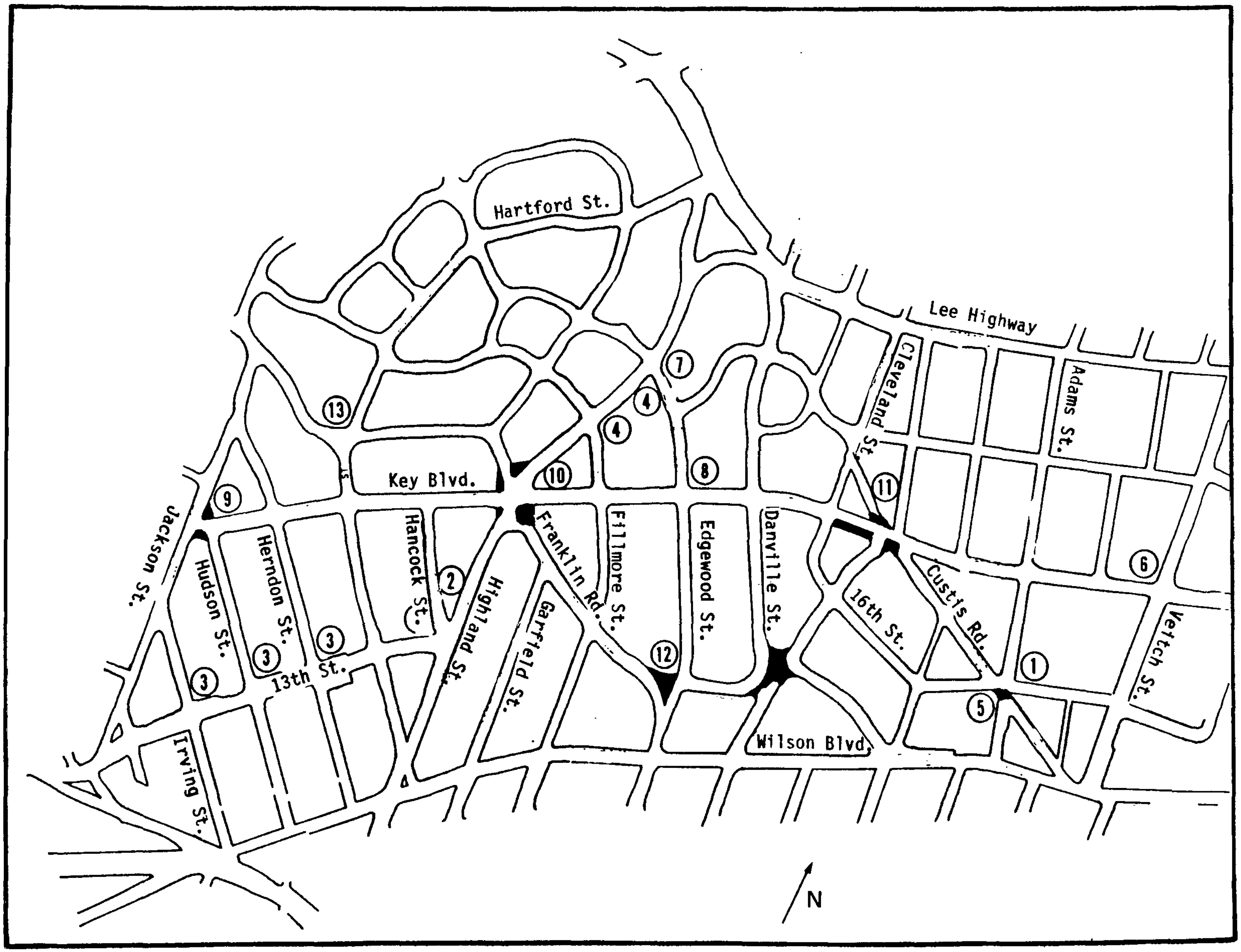


Figure 12. Lyon Village: Traffic engineering improvements.

the "after" condition (September 1978). As mentioned, the primary commuter routes were 13th, Highland, Danville, and Cleveland Streets, Key Boulevard, and Custis Road. Vehicular volumes decreased on 13th for all these roads except Danville and Cleveland Streets. No volumes were recorded for Cleveland and no improvements were implemented at Danville to discourage its use.

Vehicular volumes were recorded for several secondary commuter routes: Irving, Hudson, Herndon, Hartford, Hancock, Fillmore, Edgewood, and 16th Streets. Volumes decreased for all these roads except Hudson and Herndon. Hudson Street is one-way southbound from Key Boulevard to 13th Street and on to Wilson Boulevard. A "No Left Turn" sign was installed on 13th Street eastbound at Herndon. Thus, traffic during the afternoon peak hours may have increased slightly on Hudson and Herndon (32 [19%] and 30 [13%] vehicles, respectively.)

Vehicular volumes also increased on Jackson Street north of 13th Street and on 18th Street (102 [10%] and 101 [47%] vehicles, respectively). Some motorists may have chosen these roads as alternate routes through Lyon Village.

An increase in vehicular volumes was recorded for Veitch Street, one of the boundary roads, while a decrease was recorded for Kirkwood Road, another boundary road. Volumes on Wilson Boulevard increased slightly at one location and decreased slightly at two other locations. No data were recorded for Lee Highway, the fourth boundary road. These data seem to indicate that commuters remained on Lee Highway and utilized Veitch Street to travel to Wilson Boulevard instead of traveling through Lyon Village. Likewise, some motorists may have remained on Wilson Boulevard or may have gained access to Lee Highway at some location further west.

From the vehicular volume data taken in April and September 1978, it appears that the traffic engineering measures had a positive overall effect in immediately reducing vehicular volumes through Lyon Village.

To analyze the long-term effect of the improvements on vehicular volumes within Lyon Village, annual traffic data were obtained from Arlington County for the period from 1976 to 1984. This analysis was limited to the data collected by Arlington County as part of its regular traffic monitoring program.

The vehicle volumes shown below indicate a sizeable decrease in the vehicle volumes within Lyon Village (i.e., on Key Boulevard and on Highland Street). The sizeable increase in volumes on one of the boundary roads (Veitch Street) suggests that it may have become the preferred alternative for traffic formerly passing through Lyon Village. The decreased volumes on the other boundary roads (Kirkwood Street, Wilson Boulevard and 13th Street) are not related to the Lyon Village changes.

Location		% Change 1976-1984	% Change 1978-1984
Targeted Locations			
Highland St.	- South of Key Blvd	-44.75	-24.29
	South of 20th St	3.84	-8.22
Key Blvd	- West of Danville St	-57.93	-51.99
"Control" Locations			
Kirkwood St	- North of Washington Blvd, Northbound	-0.55	-10.56
	- North of Washington Blvd, Southbound	-21.36	-14.61
Veitch St	- North of Key Blvd	218.79	46.02
Wilson Blvd	- East of Danville St	0.45	-2.88
	East of Highland	16.99	-5.24
	East of Veitch	-5.76	-7.16
13th Street	- West of Hudson, Eastbound	-23.67	-14.80
	West of Hudson, Westbound	-43.68	-32.84

However, other significant improvements within the area during the intervening 6 years are likely to have affected the vehicular volumes. The subway opened in 1979/80 and commuter vehicular traffic may have decreased as a result. In 1978, Lee Highway near Lyon Village consisted of three lanes and has since been widened to six lanes, thus facilitating traffic flow. I-66 was opened in 1982 which may have reduced commuter traffic through Arlington.

Construction along Wilson Boulevard near the Clarendon and Court House subway stations may also have diverted traffic from the area.

Another purpose of the traffic engineering measures was to reduce vehicular speeds on Key Boulevard. Unfortunately, no data are available on vehicular speeds immediately before and after the improvements were implemented. However, speed data were recorded by Arlington County on May 1, 1970 and January 24, 1985. Speed reductions of 2.3 mi/h westbound and 4.0 mi/h eastbound have occurred on Key Boulevard. The 85th percentile speed was unchanged westbound and decreased 1 mi/h eastbound. However, these data encompass a 15-year span and it is not possible to determine the reason for the speed reductions. It is possible that the speed reductions occurred before the improvements were implemented in 1978. On the other hand, we are not aware of any other changes on Key Boulevard during the 15-year period. Thus, the speed reductions <u>may</u> be attributed to the improvements.

<u>Other Improvements</u>

The 1977 Lyon Village Neighborhood Preservation Plan also addressed other issues to enhance and conserve the overall residential characteristics of the area: parking; curbs, gutters, and sidewalks; street lighting; and park beautification.

The Citizen's Association identified two major parking problems. First, inadequate provision for employee parking in the Clarendon commercial areas resulted in neighborhood streets being used for parking. The Association was also concerned that this practice would increase when the subway stations opened. Second, parking on both sides of narrow streets caused concern for access for emergency vehicles as well as concern for safety resulting from decreased visibility.

The Citizen's Association identified streets with these types of parking problems and recommended that each block petition for those parking regulations and restrictions appropriate to its situation. Many of these streets have been signed accordingly.

CASE STUDY: ROYAL CREST RANCHEROS, CLARK COUNTY, NEVADA

The Royal Crest Rancheros (RCR) subdivision was developed in the 1960s for homeowners looking for single-family homes on large lots with curved meandering streets. In the 1970s the area around RCR was developed at a much higher density. The traffic in the area uses two streets as collector streets to reach the four major arterials that border the area. The collectors are Harmon Avenue and Spencer Street. The arterials are Tropicana and Eastern Avenues, Flamingo Road, and Maryland Parkway. Through movements from the north and south sides of the development area attempt to use the collectors to avoid using the congested arterials. The section of Spencer Street between Harmon Avenue and Gabriel Drive is quite curved. This section of road was part of the original RCR neighborhood. As the area around it developed, Spencer Street was intended to link up with the arterial streets. While Spencer Street serves as a collector, the short section running through the RCR development was not intended or designed to function as a collector street. The heavy volumes and inappropriate vehicle speeds caused area residents to appeal to the county government to take corrective action.

In 1978, responding to the citizens' request, a barrier was placed across Spencer Street at the intersection of Spencer Street and Tropicana Avenue. This reduced the volume of traffic on Spencer Street enough to satisfy the RCR residents. By 1980, residents of RCR not residing near the curved section of Spencer Street and other area residents began to lobby for the removal of the barrier. The principal reasons given were that the county was limiting access to a street that all county residents were entitled to use, and, more importantly to the county commissioners, there were claims that response times by emergency vehicles had been unnecessarily lengthened because of the barrier. In response to these concerns, the barrier was finally removed.

The county government next instituted a 15 mi/h speed limit on the curved section of Spencer Street and placed a four-way stop sign at the intersection of Spencer Street and Gabriel Drive. Data collected to assess the effectiveness of these treatments have shown that neither has been very effective in controlling speeds or volumes on Spencer Street.

In 1985, in response to requests from the RCR residents, the county undertook a traffic study of the RCR neighborhood and surrounding areas to deal with the problems on Spencer Street. After collecting baseline data to use for comparison with the effects of potential countermeasures, several alternative control scenarios and possible realignments of Spencer Street were proposed. The control scenarios were rated to compare the projected impacts on diversion of traffic, restriction of access, and circumvention by motorists. Three scenarios were recommended for experimentation. Detailed cost analyses of the realignment schemes were also recommended as another possible step in the process to solve the Spencer Street problem.

Later in 1985, each of the three traffic control plans was implemented and evaluated for 30-day periods. The three strategies are shown in figures 13 through 15. More detailed plans for the actual traffic diverters are shown in figures 16 and 17. Cost estimates for each diverter design are also indicated. While all three strategies reduced volumes on the problem section of Spencer Street, volumes on the surrounding streets were increased. There were several attempts to remove, damage, or circumvent the temporary devices used in all three schemes. These results caused the county officials to drop diversion tactics as a potential solution to the problem.

County officials are in the process of determining citizen reaction to a realignment project, as well as the use of special assessments to fund the improvement.

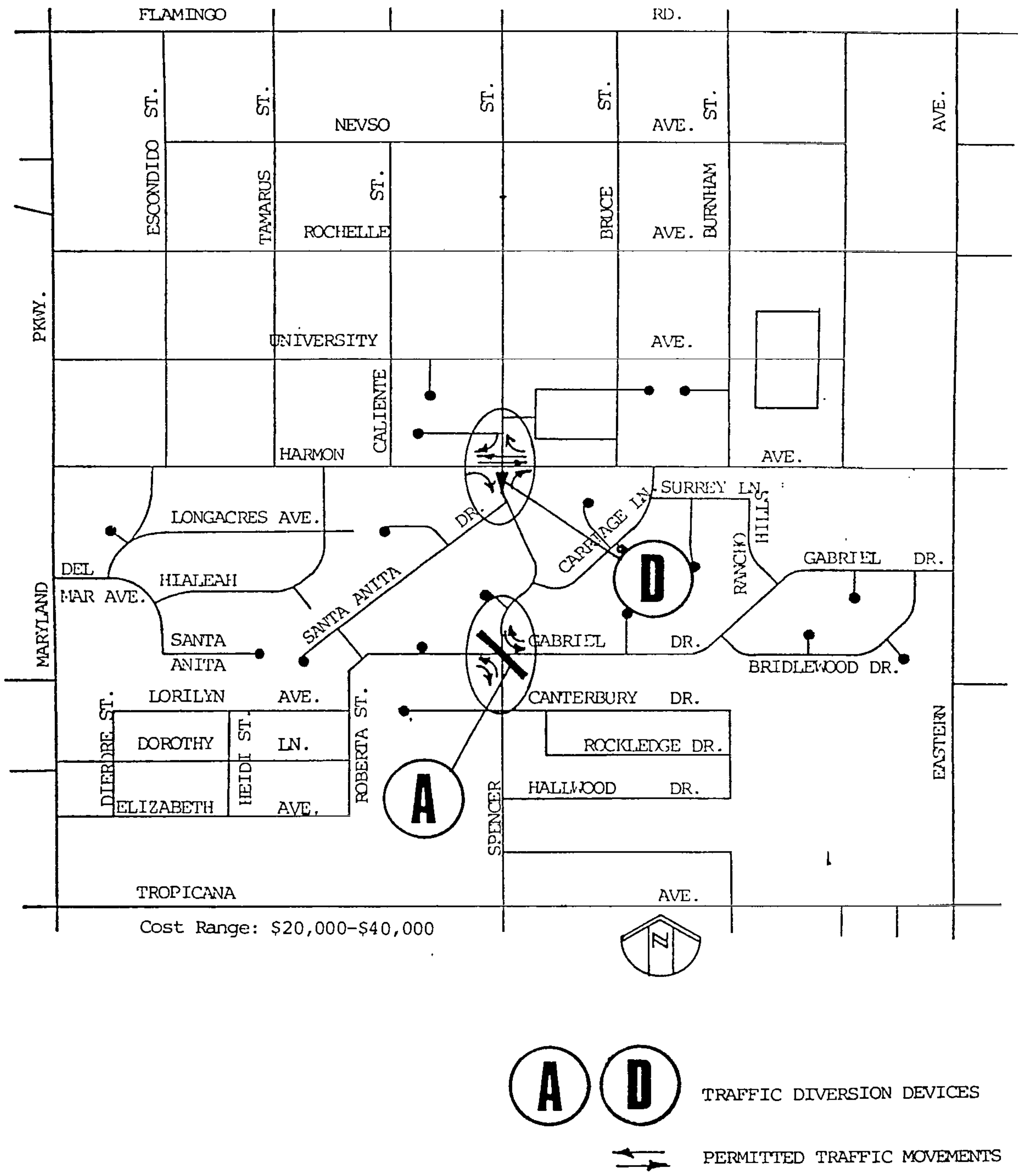


Figure 13. Diversion strategy I.

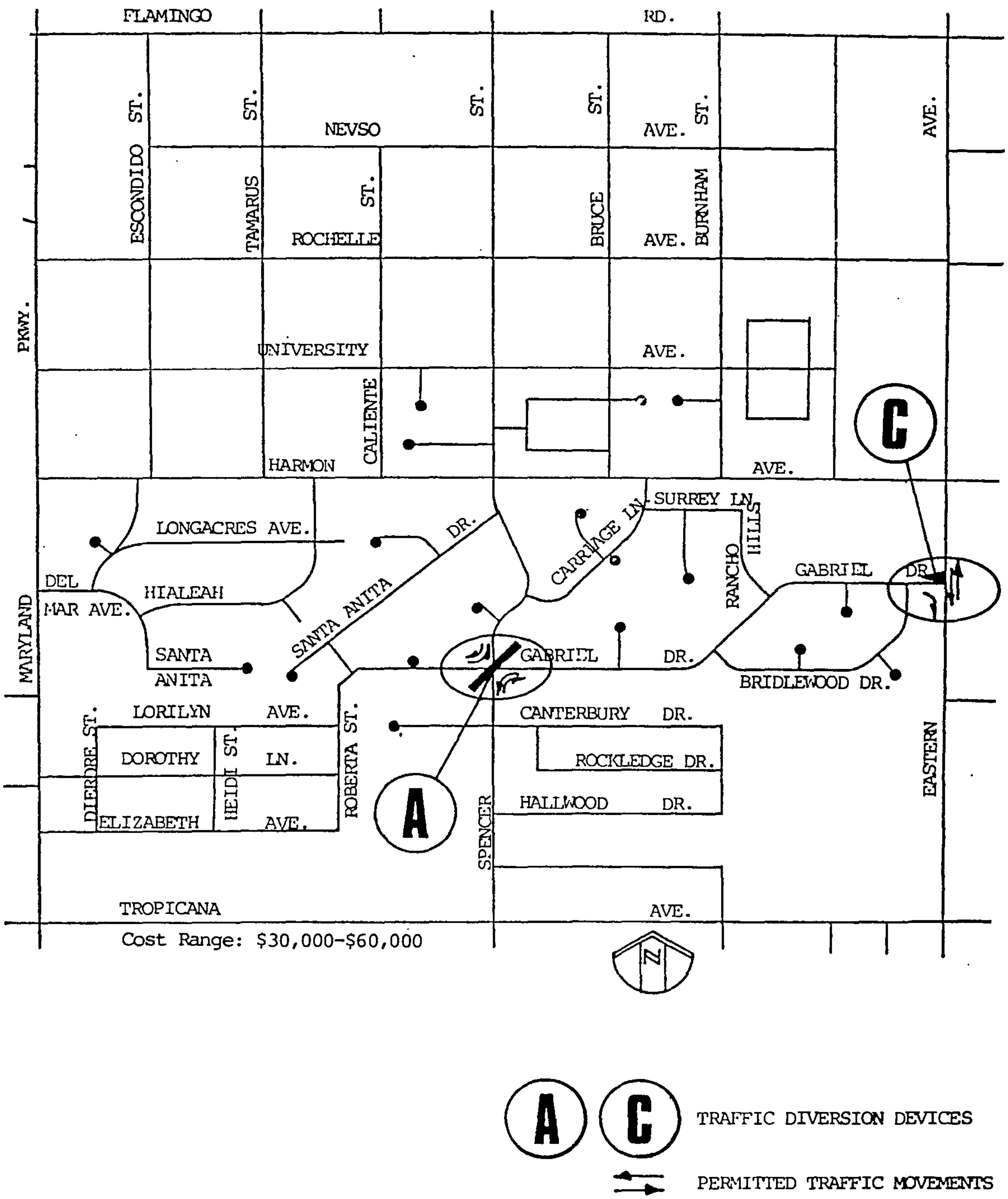
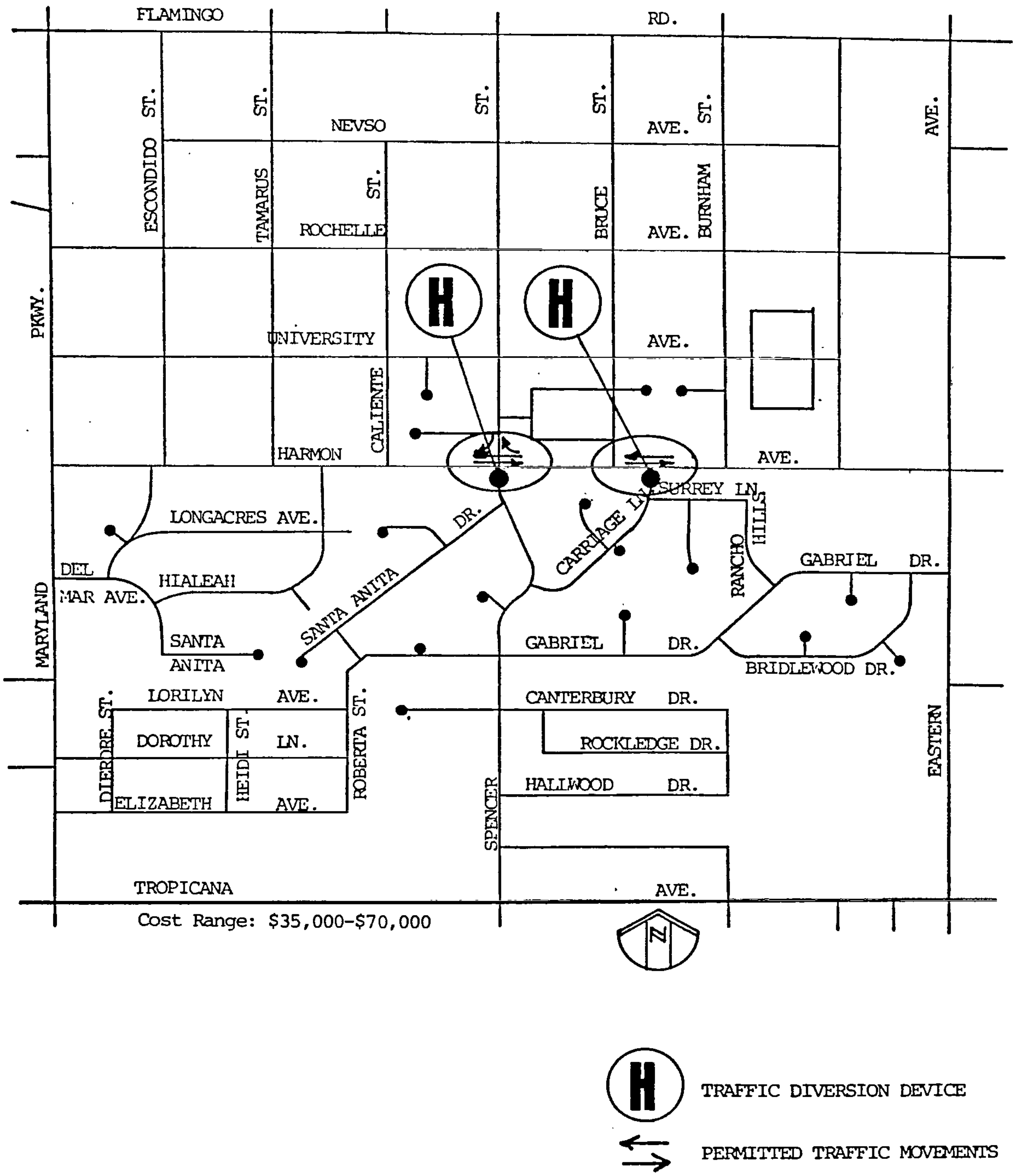


Figure 14. Diversion strategy II.



Cost Range: $35,000-$70,000

Figure 15. Diversion strategy III.

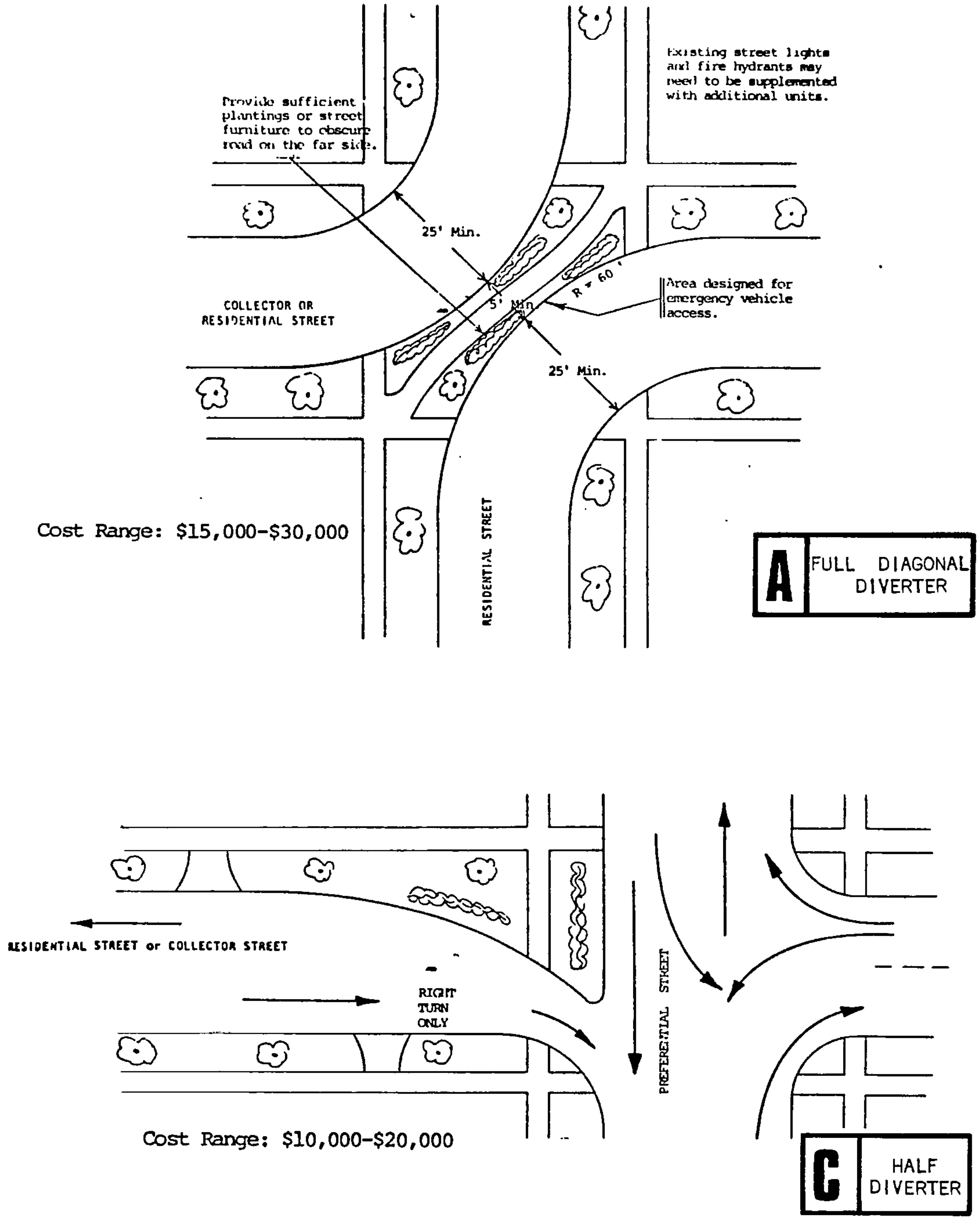
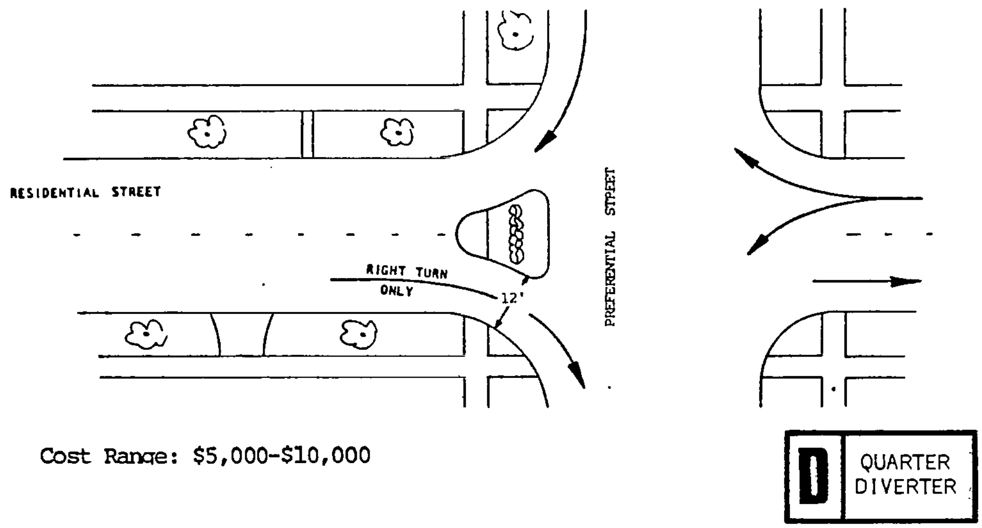


Figure 16. Traffic diversion devices A and C.



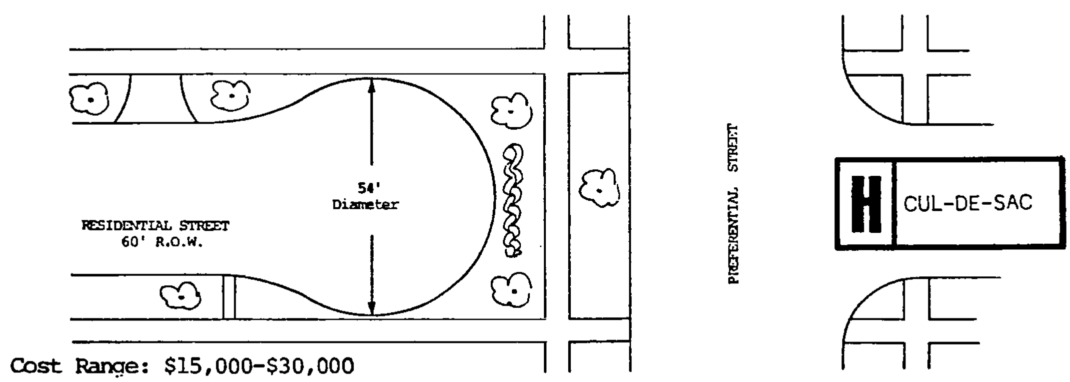


Figure 17. Traffic diversion devices D and H.

CASE STUDY: BERKELEY, CALIFORNIA

As early as 1964, there was concern about the use of Berkeley's neighborhood streets by vehicles making through trips. Some traffic diverters were installed to discourage the use of side streets and force traffic back onto the collector and arterial streets. The few locations where diverters were installed seemed to divert the traffic from the neighborhood areas. Seeing their success in a few locations, Berkeley traffic officials continued to install diverters on a case-by-case basis. In 1968, the Berkeley City Council adopted a new Circulation Section of the Berkeley Master Plan. In 1972, a consultant study was begun to conduct a Neighborhood Traffic Study (NTS) to consider the goals of the previously approved Circulation Section of the Master Plan and the needs of individual neighborhood residents.

In the initial stages of the NTS and throughout the study, the consultants met with neighborhood groups to develop a plan that would be acceptable to the residents. City-wide mailers were distributed on a periodic basis to keep the residents apprised of developments in the NTS. The final product of the work of the NTS was a Traffic Management Plan (TMP) for the city.

The TMP called for the use of several different types of devices, including traffic circles, diverters, semi-diverters, street closures, stop signs, and miscellaneous other controls. Traffic circles were used to reduce traffic speeds and volumes. They were constructed of concrete bollards interconnected by boards. The diverters were used to create a diagonal blockage of a four-legged intersection. The diverters were constructed of guardrail or bollards and board. In some locations, installation involved reconstruction of the intersection using raised curb diverter designs. The semi-diverters were used to allow travel in only one direction. The semi-diverters were constructed of bollards and boards. Full closure treatments created cul-de-sacs in the existing gridiron network. The full closures were effected by the use of bollards and boards. The use of stop signs was a major part of the TMP as well. Over 150 locations had one or more stop signs installed. The miscellaneous treatments were mostly turn restrictions and channelization changes at selected intersections.

During 1975, the TMP was implemented and a close monitoring of the effects of the plan was initiated. After a 6-month trial period, an interim report of the experience with the plan was produced.

Some citizens began to express opposition to the street diversions after the plan was implemented. In 1976 an initiative to remove all the diverters in the city was placed on the ballot during city-wide elections. The initiative was defeated.

The election defeat did not discourage those citizens who were opposed to the diverters. The dissenters filed suit to have the diverters removed. Another initiative was placed on the ballot and was defeated again.

The controversy surrounding the diverters has not stopped. Supporters on both sides continue to push their causes, but the diverters remain. The court decision allowing their placement is based on Section 21101.1 of the California Vehicle Code, which allows local jurisdictions to prohibit entry or exit to/from streets by means of islands, barriers, curbs, or other design features to implement the circulation element of a general plan. The key item contested by the opposing parties was whether the diverters constituted a roadway design element or whether they were a traffic control device. The courts ruled the diverters to be design features and allowed them to stay.

The effects of the TMP have been as expected. Traffic volumes generally have decreased on residential streets that were targeted to have reduced volumes as part of the plan. Volumes on commercial and mixed use arterial and collector streets have generally increased. The streets with volume increases have not experienced serious increases in congestion, partly because of operational improvements made to the streets where volume increases were anticipated.

There appeared to be a slight shift of accidents from neighborhood streets to the arterials and collectors in the 6-month period following implementation of the plan. The short period of analysis, however, makes any conclusions associated with the limited accident data spurious.

The character of the neighborhoods has appeared to change as well. Although not readily measurable, decreased neighborhood traffic volumes have created a pro-pedestrian atmosphere in the neighborhood. The lower volumes and altered traffic patterns eliminated the number of conflict points and the frequency of pedestrian-vehicle conflicts. Lower volumes also created a more pedestrian-friendly environment (less noise and exhaust).

CHAPTER V

REVISED GUIDANCE ON PEDESTRIAN PATHWAYS AND SIDEWALKS

INTRODUCTION

This chapter describes the development of design guidance for installing pedestrian pathways and sidewalks. Existing warrants/design guidance for sidewalks were identified through the literature search and through contacts with local operational personnel. Additional analysis of the pedestrian exposure data was undertaken to identify the site characteristics, roadway characteristics, pedestrian volumes, and vehicle volumes of those places that would most benefit from the provision of pedestrian pathways and sidewalks.

Guidance/warrants for pedestrian pathways and sidewalks were developed based on this information. A draft version was presented to a sample of practicing traffic engineers to solicit their opinions regarding the utility and appropriateness of the guidance/warrants.

This chapter consists of four major sections:

- Analysis of Exposure Data for Sidewalks.
- State-of-the-Practice Review.
- Draft Guidelines for Sidewalk Installation.
- Practitioner Reaction to the Draft Guidelines.

ANALYSIS OF EXPOSURE DATA FOR SIDEWALKS

The previous pedestrian exposure measure study determined that sites with no sidewalks (or pathways) were hazardous for pedestrians in terms of the pedestrian volume and PxV exposure hazard scores. The pedestrian hazard score (+2.6) and the PxV exposure hazard score (+2.2) indicated that accidents were more than two times more likely to occur at these places than would be expected on the basis of exposure. The pedestrian volume and PxV exposure hazard scores associated with sidewalks on one side were relatively small (+1.2 and +1.1), as were those associated with sidewalks on both sides (-1.2 and -1.2). However the hazard scores were consistent and in the predicted direction. Sites with no sidewalks were the most hazardous, sites with one sidewalk were less hazardous, and those with two sidewalks were the least hazardous.

Only two types of sidewalk locations were further analyzed in this study: sites with no sidewalks and sites with sidewalks on both sides. For sites with sidewalks on only one side, it was not known whether the accidents occurred on the side of the roadway with the sidewalk or on the side without the sidewalk. Also, these locations represented only 9.5 percent of the accidents, 7.8 percent of the pedestrian exposure, and 8.3 percent of the PxV exposure. When the data were categorized by several site factors, the percentages in the sidewalk on one side category were often very small. Thus, in the tables in this section the percentages may not add up to 100 since data for sidewalks on one side are not shown.

Land Use

While 47.5 percent of the sites in totally residential areas had sidewalks, they carried the vast majority of the PxV exposure (91.7%). Residential areas with no sidewalks, on the other hand, had 23.4 percent of the accidents and only 2.7 percent of the exposure. Thus, sites in residential areas with sidewalks were safe and those without were hazardous.

Sites in commercial areas with sidewalks carried the vast majority of the P and PxV exposure. In terms of the PxV exposure measure, the percentage of accidents in commercial areas with sidewalks (and without sidewalks) was in proportion to the percentage of exposure at sites with sidewalks (or without sidewalks). Thus, sidewalks do not appear to have an effect on the degree of hazard associated with commercial areas.

Also, for mixed residential areas, sidewalks existed at those sites that carried the vast majority of the P and PxV exposure. However, sites without sidewalks in mixed residential areas were hazardous and those with sidewalks were safe.

Land Use at Intersection	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
100% Residential							
No Sidewalks	23.4	33.5	12.1	2.7	-1.4	+1.9	+8.7
Sidewalks	67.9	47.5	79.9	91.7	+1.4	-1.2	-1.4
Commercial							
No Sidewalks	15.0	12.1	4.3	12.5	+1.2	+3.5	+1.2
Sidewalks	74.8	66.8	88.8	79.0	+1.1	-1.2	-1.1
Mixed Residential							
No Sidewalks	30.8	50.9	14.3	6.8	-1.6	+2.2	+4.5
Sidewalk	59.8	33.7	76.4	84.9	+1.8	-1.3	-1.4

Functional Classification

Most of the PxV pedestrian exposure on major arterials, collector-distributors, and local streets occurred where there were sidewalks. Most of the accidents occurred at these locations also. Although the trend was consistent across all roadway types, the degree of hazard was less at sites with sidewalks, but it was not a large difference.

Functional Classification	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Major Arterial							
No Sidewalks	11.9	24.1	5.5	12.2	N/A	N/A	N/A
Sidewalks	75.9	52.5	91.4	87.5	+1.4	-1.2	-1.2
Collector/Distributor							
No Sidewalks	17.9	15.7	4.2	14.4	+1.1	+4.3	+1.2
Sidewalks	70.9	74.5	92.7	83.5	-1.0	-1.3	-1.2
Local Street							
No Sidewalks	16.9	34.3	12.4	2.2	N/A	N/A	N/A
Sidewalk	75.7	46.7	81.6	94.1	+1.6	-1.1	-1.2

Number of Lanes

Again, the majority of the P and PxV exposure was at sites with sidewalks, regardless of the number of lanes. The percentage of accidents at sites with sidewalks was in proportion to the percentage of exposure at these sites, regardless of the number of lanes. Sites without sidewalks were hazardous. Two-lane roadways without sidewalks were especially hazardous. However, the PxV hazard score for sites with two lanes or less was based on only 3.0 percent of all sites with two lanes or less.

Number of Lanes	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Two or Less							
No Sidewalks	25.2	38.8	10.8	3.0	-1.5	+2.3	+8.4
Sidewalks	67.2	42.2	77.9	74.4	+1.6	-1.2	-1.1
More than Two							
No Sidewalks	20.9	22.6	5.3	14.6	-1.1	+3.9	+1.4
Sidewalks	67.2	66.5	93.7	84.3	+1.0	-1.4	-1.2

Block Length

For block lengths less than 500 feet, over 95 percent of the PxV exposure in the two categories occurred at sites with sidewalks. Therefore, the hazard scores for these block lengths without sidewalks are not presented. The hazard scores for block lengths less than 250 feet with sidewalks were neither safe nor hazardous, and those for block lengths between 251 and 499 feet with sidewalks were safe. The PV exposure for block lengths greater than 500 feet was more equally divided between sites without sidewalks and those with sidewalks. The resulting hazard scores were neutral, neither safe nor hazardous.

Block Length	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Less than 250 ft							
No Sidewalks	14.2	32.4	5.4	0.6	N/A	N/A	N/A
Sidewalks	71.5	42.4	84.4	95.1	+1.7	-1.2	-1.3
251 ft - 499 ft							
No Sidewalks	19.3	26.5	4.3	0.9	N/A	N/A	N/A
Sidewalks	71.1	60.2	92.2	97.6	+1.2	-1.3	-1.4
More than 500 ft							
No Sidewalks	32.9	49.0	19.0	30.6	-1.5	+1.7	+1.1
Sidewalk	61.0	34.5	67.2	48.5	+1.8	-1.1	+1.3

The data indicated that short blocks tended to have sidewalks more than longer blocks. In fact, short blocks with no sidewalks had so little pedestrian activity that it was not appropriate to compute a hazard score. The hazard scores for the longer blocks indicated that sidewalks had no major effect on hazard when block length was greater than 500 feet.

Shoulder

The exposure data base contained information on the shoulder surface materials. The number of accidents, sites, and exposure in each of the material types was too small to determine hazard scores. These were combined in this table as some type of shoulder present.

In terms of the PxV exposure measure, sites with no shoulders and no sidewalks were as safe as sites with sidewalks and no shoulder. However, the vast majority of the exposure occurred at sites with sidewalks.

	% of National Projections				Hazard Score		
Shoulders	Acc.	Sites	Peds	P x V	Site	Peds	P x V
No Shoulders							
No Sidewalks	10.8	24.7	6.7	10.0	-2.3	+1.6	+1.1
Sidewalks	80.2	55.8	85.6	81.8	+1.4	-1.1	-1.0
Shoulders							
No Sidewalks	80.0	79.8	58.4	48.8	+1.0	+1.4	+1.6
Sidewalks	7.8	7.5	30.9	40.6	+1.0	-4.0	-5.2

For sites with shoulders, the exposure was more evenly distributed between sites with sidewalks and those without, although only 7.5 percent of the sites with shoulders also had sidewalks. The hazard scores indicated that sites with shoulders and no sidewalks were hazardous while those with sidewalks were relatively safe.

Medians

Unfortunately, the PxV exposure at sites with no medians and no sidewalks was too small to determine realistic hazard scores. However, sites with no medians and sidewalks had somewhat fewer accidents than would be expected based on the amount of PxV exposure.

Sites with medians and without sidewalks were safe for pedestrians in terms of the PxV exposure measure, but hazardous in terms of the P exposure measure. Sites with sidewalks were safe in terms of the P exposure measure. This is because the PxV exposure at these sites was high due to higher vehicle volumes.

Medians	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
No Medians							
No Sidewalks	20.5	37.1	8.0	1.3	N/A	N/A	N/A
Sidewalks	71.3	44.0	83.8	88.9	+1.6	-1.2	-1.2
Medians							
No Sidewalks	33.3	34.1	18.0	49.7	-1.0	+1.8	-1.5
Sidewalks	52.4	59.0	77.6	48.3	-1.1	-1.5	+1.1

Curbs

Since sidewalks on one side of the roadway were not analyzed, curbs on one side were also eliminated from the analysis. Ten (only 7.7%) of the sites with no curbs had sidewalks, and these sites had only 2.9 percent of the accidents. Thus, the hazard scores are not presented. However, these sites carried 26.4 percent and 41.0 percent of the P and PxV exposure, respectively.

In terms of the PxV exposure measure, the presence or absence of a sidewalk did not affect the hazard associated with sites with curbs on both sides.

Curbs	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
None							
No Sidewalks	94.3	77.8	60.2	47.1	+1.1	+1.6	+2.0
Sidewalks	2.9	7.7	26.4	41.0	N/A	N/A	N/A
Both Sides							
No Sidewalks	9.7	20.3	6.9	12.0	-2.1	+1.4	-1.2
Sidewalks	81.8	61.3	85.5	78.7	+1.3	-1.0	+1.0

Street Lighting

The P and the PV exposure for sites with no street lighting and no sidewalks represented less than 1 percent of the total exposure. This was also true for sites with no street lighting and with sidewalks. Thus, the hazard scores are not shown.

At places with regularly spaced street lighting, the lack of sidewalks increased hazard for pedestrians. Sites with sidewalks were safer when regularly spaced street lighting was provided.

Street Lighting	% of National Projections Acc.	Sites	Peds	P x V	Hazard Score Site	Peds	P x V
Regularly Spaced							
No Sidewalks	14.3	29.9	8.2	10.3	-2.1	+1.7	+1.4
Sidewalks	76.2	49.8	84.7	82.1	+1.5	-1.1	-1.1
Not regularly spaced							
No Sidewalks	29.9	28.9	8.2	14.1	N/A	N/A	N/A
Sidewalk	67.5	55.1	80.6	67.5	+1.2	-1.2	+1.0

Since the sites with irregularly spaced street lighting and no sidewalks represented less than 1 percent of all the exposure, the hazard scores are not presented. Sites with not regularly spaced street lighting and sidewalks were more common, the hazard ratios indicated that they were neither safe nor hazardous.

Summary

Not surprisingly, the majority of pedestrian exposure occurred at sites with sidewalks as opposed to those with no sidewalks. This is because people tend to walk where there are sidewalks and sidewalks tend to be built where people walk. In the exposure data base, 36.8 percent of the sites had no sidewalks but they collectively had only 9.0 percent of the pedestrian exposure and 10.7 percent of the PxV exposure. The cross-tabulations performed to further examine the hazard associated with places not having sidewalks divided this relatively small percentage of the total exposure into two or more categories. In many cases, the cross-tabulations resulted in distributions that had cells with very low frequencies, which preclude any meaningful conclusions.

The following variables were examined, but were found to have such low cell frequencies that useful conclusions could not be made:

- Roadway Functional Classification.
- Block Length.
- Shoulder.
- Medians.
- Roadway Edge Markings.

- Channelization.
- Parking Restrictions.
- Parking Meters.
- Curbs.
- Commercial Lighting.

In many cases, these variables were highly correlated with the presence or absence of sidewalks (i.e., curbs are usually found where sidewalks are present and vice versa) so that the uneven cell distributions were further exaggerated.

Several conclusions can be drawn from the other PxV hazard score analyses that were performed:

- Residential and mixed residential areas with no sidewalks are especially hazardous for pedestrians.
- Commercial areas with no sidewalks are only slightly more hazardous than commercial areas with sidewalks.
- Two-lane roadways with no sidewalks are especially hazardous, while roadways with more than two lanes and no sidewalks are only slightly more hazardous than their counterparts with sidewalks.
- Places with regularly spaced street lighting and no sidewalks are more hazardous than similarly illuminated places with sidewalks.

STATE-OF-THE-PRACTICE REVIEW

Procedure

A number of local practitioners were contacted to determine current operational practice. Nine individuals were asked nine questions about their current practices concerning sidewalk installations. These questions were:

- What warrants, guidelines and/or criteria do you use to determine whether sidewalks or pathways should be installed at the following kinds of locations?
  - New residential areas.
  - New commercial areas.
  - Existing residential areas.
  - Existing commercial areas.
  - School areas.

- How do you prioritize locations for the installation of sidewalks or pathways?

- Have you had any problems or difficulties using any of the warrants, guidelines or prioritization procedures?

- What factors do you think should be considered in developing new warrants or guidelines?

- What additional information (i.e., pedestrian volume counts) would you be willing to collect if the information were needed to use a newly developed sidewalk construction warrant?

- What are your design specifications for sidewalks and pathways?

- Do you install concrete sidewalks, asphalt pathways, gravel paths, or implement shoulder improvements depending on the anticipated level of pedestrian use? If yes, what criteria are used to determine which of the various levels of improvement are appropriate?

- What funding sources do you use to cover the costs of sidewalk construction (i.e., assess abutting property owners, capital improvement fund, etc.)?

- Are you aware of other warrants or guidelines used by other agencies for the installation of sidewalks or pathways? If so, who could we contact to obtain this information?

Nine other individuals were asked for information on research to demonstrate the safety benefit of sidewalks or the appropriateness of sidewalk design specifications. These practitioners were asked the following questions:

- Have you conducted any research or operational studies to determine the effectiveness of sidewalks or pathways in improving pedestrian safety? Do you know any other agencies that have?

- Have you conducted any research or operational studies to determine appropriate design specifications for pedestrian pathways or sidewalks? Do you know any other agencies that have?

- Are you aware of any warrants or guidelines being used to determine whether sidewalks or pathways should be installed at the following kinds of locations?
  - New residential areas.
  - New commercial areas.
  - Existing residential areas.
  - Existing commercial areas.
  - School areas.

Results

Written responses were received from 10 of the 18 individuals contacted; four more were contacted by telephone to obtain responses to the more critical questions. The most striking, but not surprising, part of the responses was the lack of quantitative procedures for determining where sidewalks should be installed. The following summarizes many of the responses concerning where sidewalks should be installed:

- Sidewalks are encouraged at all locations.
- Sidewalks are required in all new subdivisions although this requirement is frequently waived.
- Sidewalks are required in all subdivisions where the lot size is less than 18,000 sq.ft.
- Sidewalks are installed based on estimated pedestrian volumes and volume generators.
- Sidewalks are required in all new developments.
- Sidewalk installations are prioritized by pedestrian volume, vehicle volume, and number of accidents. The first priority is for school locations.
- Sidewalks are provided along all streets excepting where, in the opinion of the council, they are unnecessary.

Two of the localities contacted tied the sidewalk warranting process to the functional roadway classification. One West Coast suburban area uses the following guidelines:

Sidewalks are required on:

- Both sides of arterials and neighborhood collectors.
- Both sides of urban local access streets more than 600 feet long.
- One side of urban local access streets less than 600 feet long.
- One side of suburban local access streets.
- Both sides of all commercial streets.

A Washington, D.C., suburb bases the sidewalk requirements on a combination of vehicle volumes and roadway functional class:

"The following guidelines have been developed to help clarify and direct the installation of future sidewalks. As is the case with many sets of guidelines, their use requires judgment and a determination of which guidelines are most applicable in a given situation.

1. Traffic Volume (AWT) = Average Weekday Traffic:
   a. Under 500 AWT - Sidewalk not needed on either side of street.
   b. 500 AWT to 5,000 - Sidewalk needed one side of street.
   c. Above 5,000 AWT - Sidewalks needed on both sides of street.

2. Street Classification: (as set forth in Major Thoroughfare Plan)
   a. Principal Arterial - Sidewalks needed on both sides.
   b. Minor Arterial - Sidewalks needed on both sides.
   c. Collector - Sidewalks needed on both sides.
   d. Local - Sidewalks needed on one side."

Only a few respondents indicated that they were aware of other warrants or guidelines used by other agencies. The majority did, however, indicate that such guidelines were needed. Some of the jurisdictions also indicated a willingness to collect additional data (i.e., pedestrian volume counts, vehicle volume counts, and number of accidents) that might be needed to use a newly developed sidewalk construction warrant. Others indicated that warrants should be based on functional class and that collecting additional volume data was expensive and not necessary.

Finally, most of the jurisdictions indicated that they did have specified engineering requirements (i.e., width, concrete thickness, slope) for constructing sidewalks when they are built. Many respondents indicated also that priority is given (or should be given) to school areas.

DRAFT GUIDELINES FOR SIDEWALK INSTALLATION

Eight general principles of sidewalk installation were developed after considering the results of the literature review, the analysis of the exposure data, and the practitioners' responses to the state-of-the-practice:

- The term "sidewalk" refers to a paved surface intended for walking, typically concrete, asphalt or brick. A sidewalk involves a walkway on the side of a road, as differentiated from walkway systems which link areas away from a roadway. The term "walkway" is a broader term, which can include all types of pedestrian pathway systems.

- All roads should have some type of walking facility out of the traveled way, whether a shoulder or separate walkway.

- Provision should be made to accommodate future pedestrian usage even though usage may be minimal in the early stages of development. Right of way should be acquired or reserved early in the planning cycle. Construction of walkways may be deferred if there is no pedestrian activity, but should be required when there is evidence of pedestrian demand.

- Warrants based on pedestrian volume are not necessary or practical, since volume data are not regularly collected and cannot be easily forecast. Development density is an adequate surrogate for pedestrian usage in determining the need for sidewalks.

- Many of the benefits of sidewalks are not quantifiable, and the magnitude of the safety benefit is unknown. However, guidelines for installation can be based on an assessment of the functional aspects of roadway design and pedestrian travel needs.

- Provision of sidewalks should be related to functional classification of streets. For example, collector streets are more likely to have "through" pedestrian traffic even though residential densities on the street itself are low. Collectors would normally be used by pedestrians to access bus stops and commercial development on the arterial into which they feed.

- For existing residential streets, costs of sidewalks may be prohibitive in comparison to the benefits that would accrue. Some older neighborhoods in hilly terrain have retaining walls in spaces where the sidewalk would have to be located. In residential areas with single family homes, the need for a sidewalk should be determined by residents along the street.

- Sidewalks may include traditional concrete surfaces or paved asphalt facilities. Some developers and communities argue against sidewalks because they detract from the creation of a park-like residential atmosphere. Where a park-like atmosphere is desired, asphalt walkways are appropriate.

These general principles were used to develop a set of draft guidelines for sidewalk installation.

PRACTITIONER REACTION TO THE DRAFT GUIDELINES

Once the sidewalk installation principles were developed, the project staff felt it was appropriate to have some "feedback" from 24 practicing engineers with responsibility for overseeing sidewalk location and construction. A target group was made up of those individuals previously contacted in the project and members of the Transportation Research Board (TRB) pedestrian committee. The group included primarily local government contacts, with an attempt at good geographic distribution. Each person was sent a draft copy of the sidewalk installation principles and a form (figure 18) which asked questions about the general acceptability of guidelines such as these and specific inquiries about some of the details of the principles. General discussion of the points covered by the form as well as any pertinent comments were encouraged. A total of 11 responses was received.

The first question asked about the need for a set of guidelines. The majority (73%) of the group felt that guidelines are necessary, while 9 percent (one person) did not. Eighteen percent did not answer with a "yes" or "no" reply. The reasons for having guidelines as well as a discussion of the potential benefit of guidelines centered around a perceived need for guidance about sidewalk location. Five of the respondents felt that having a uniform standard is important. Three people thought guidelines would be a good way to increase awareness among engineering professionals and other groups (e.g., policy makers, developers) of their responsibility to provide for the needs of the pedestrian. Two felt that a set of guidelines could serve as a lever to get non-government entities to provide sidewalks. One respondent felt that guidelines would give the jurisdiction responsible for sidewalks a defensible position when requiring or denying sidewalk installations. One person felt the guidelines could require more sidewalks than the local jurisdiction could fund, while another person thought guidelines would ease review and funding problems. One respondent felt that national guidelines were not a good idea since different areas have different needs.

Sixty-four percent of the group felt the presentation format of the guidelines was acceptable, while 36 percent of the respondents did not give a "yes" or "no" reply. One respondent felt that the format could be improved by

SIDEWALK GUIDELINES

1. Do you think that guidelines are needed for the installation of sidewalks and pathways? Why? ______________________________
____
____

2. How would the guidelines be of benefit to state and local agencies?
____

3. Are the guidelines presented in a format that is usable? How could the format/presentation be improved? ______________________
____

4. Do the guidelines reasonably reflect where you think sidewalks should and should not be installed? ______________________
____

   a. Is the concept of warrants based on functional classification valid? ______________________________
   b. Are the dwelling density thresholds reasonable? __________
   ____
   c. Are the basic criteria appropriate? ______________________
   ____

5. Is there a need for different types of walkway paving surfaces? ____ Should the less expensive and less durable surfaces be used at all? ____ If so, where? ______________________________
____
____

6. Would the existence of a nationally suggested set of guidelines affect your concern over tort liability claims? ____ How? __________
____
____

7. How would the application of these guidelines affect current practice? Would you expect fewer, more or about the same number of sidewalks to be installed? ______________________________
____

8. Any comments, compliments, or complaints? ______________________
____

Completed by:
Name: ______________________
Position: ______________________
Phone: (____) ______________________

Figure 18. Practitioner response form.

changing to a handbook style using illustrations and diagrams. One person thought the guidelines could include information about the location of landscaping, street furniture, and utilities.

The first part of question 4 asked about the reasonableness of sidewalk locations recommended by the guidelines. Fifty-five percent of the group felt the guidelines were a reasonable reflection of where sidewalks should and should not be installed. One respondent commented that his jurisdiction allows for the elimination of a required sidewalk if an approved alternative pedestrian pathway is provided. Another person commented that the local policy is to require sidewalk construction at the frontage areas of all new construction.

The second part of question 4 was about warrants based on functional classification. Most (73%) of the group felt having a warrant based on functional classification is valid. Nine percent did not, and 18 percent did not give a "yes" or "no" answer. One of the respondents felt the guidelines should be more detailed in this area, but did not specify how to do this. One person felt the guidelines were valid only in rural areas. Another person commented that it seems valid in most cases, except for the "collector" classification.

The third part of question 4 asked about density thresholds. Forty-five percent of the respondents felt the thresholds were reasonable while 9 percent did not. Forty-five percent of the group did not give a "yes" or "no" response. One jurisdiction commented that the density thresholds would not be useful in larger cities, and the use of pedestrian volume counts was suggested instead.

The fourth part of question 4 dealt with the basic criteria. Thirty-six percent of the group felt the basic criteria were appropriate, and 64 percent of the respondents did not answer with a "yes" or "no" reply. One person suggested that a range of criteria/conditions be used. Another person commented that advocating the use of the shoulder as a walking area caused some consternation. One respondent felt that it is not necessary to install sidewalks on both sides of the street. Two agencies thought that the planting strip criteria should be widened to at least 4 feet. One person felt the sidewalk width standards might be too wide. One respondent felt care should be taken in establishing width minimums, because legal problems could arise if there is not enough room to follow the width standard.

A third (36%) of the group felt there is a need for different types of walkway paving surfaces, while nearly half (45%) did not. Eighteen percent of the group did not respond. For the second part of question 5, 27 percent of the respondents thought that less expensive and less durable surfaces could be used. About half (55%) of the group felt these types of surfaces should not be used at all. Eighteen percent did not respond. Responding to where these less durable surfaces might be appropriate, three people felt that their use was appropriate on a temporary basis. One respondent felt lower density areas might be appropriate for using these natural types.

Question 6 dealt with tort liability. Seventy-three percent of the group thought the existence of a set of guidelines would affect their level of concern regarding torts. Eighteen percent felt it would not affect their concern, while 9 percent did not respond. Two of the group thought a nationally accepted set of guidelines would help defend against tort claims, while two others felt that any published guideline is a potential issue in a suit. One person thought there would be an incentive (tort-related) to provide sidewalks, while another person wondered about maintenance-related tort problems.

Responding to question 7, 17 percent of the group felt the guidelines would cause the installation of more sidewalks, while 9 percent thought that fewer sidewalks would be installed. Fifty-five percent of the people thought things would be unchanged, and 9 percent did not respond to this question.

Question 8 solicited general comments. One person felt that the guidelines should give a little more discretion to the local jurisdiction, while another thought that the guidelines should cover warrants for curb ramps. One respondent commented that in the final analysis, the location of public facilities is usually a political decision.

RECOMMENDED GUIDELINES FOR SIDEWALK INSTALLATION

The practitioners' responses were used to modify the draft guidelines and generate a final version of the recommended guidelines for sidewalk installation. These guidelines are shown in figure 19. The sidewalk requirements shown are dependent on land use, roadway functional classification, and, in the case of residential areas, dwelling unit density.

The guidelines indicate where sidewalks should be installed. Obviously the width of a sidewalk should depend on where it is installed and the anticipated usage. The following are suggested minimum specifications for the width of the sidewalk to be installed:

- Central business districts - Conduct level of service analysis according to methods in 1985 Highway Capacity Manual.
- Commercial/industrial areas outside a central business district - Minimum 5 feet wide with 2-foot planting strip or 6 feet wide with no planting strip.
- Residential areas outside a central business district:
  - Arterial and collector streets - Minimum 5 feet with minimum 2-foot planting strip.
  - Local streets:
    - Multi-family dwellings and single-family dwellings with densities greater than four dwelling units per acre - Minimum 5 feet with minimum 2-foot planting strip.
    - Densities up to four dwelling units per acre - Minimum 4 feet with minimum 2-foot planting strip.

Land-Use/Roadway Functional Classification/Dwelling Unit	New Urban and Suburban Streets	Existing Urban and Suburban Streets
Commercial & Industrial/ All Streets	Both sides.	Both sides. Every effort should be made to add sidewalks where they do not exist and complete missing links.
Residential/Major Arterials	Both sides.	
Residential/Collectors	Both sides.	Multi-family - both sides. Single-family dwellings - prefer both sides; required at least one side.
Residential/Local Streets More than 4 Units Per Acre	Both sides.	Prefer both sides; required at least one side.
1 to 4 Units Per Acre	Prefer both sides; required at least one side.	One side preferred; at least 4-ft. shoulder on both sides required.
Less than 1 Unit Per Acre	One side preferred; shoulder both sides required.	At least 4-ft. shoulder on both sides required.

NOTES:

(1) Any local street within two blocks of a school site that would be on a walking route to school - sidewalk on at least one side.

(2) Sidewalks may be omitted on one side of new streets where that side clearly cannot be developed and where there are no existing or anticipated uses that would generate pedestrian trips on that side.

(3) Where there are service roads, the sidewalk adjacent to the main road may be eliminated and replaced by a sidewalk adjacent to the service road on the side away from the main road.

(4) For rural roads not likely to serve development, provide a shoulder at least 4 feet in width, preferably 8 feet on primary highways. Surface material should provide a stable, mud-free walking surface.

Figure 19. Guidelines for installing sidewalks.

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