

Guidelines for the Installation of Crosswalk Markings

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There has been a great deal of confusion and misunderstanding regarding the use of crosswalk markings in the United States. Uniform guidelines for installing crosswalks are needed to increase the uniformity of crosswalk applications and to prevent the unnecessary proliferation of crosswalk marking. A literature review, a survey of current practice, and an analysis of pedestrian and vehicle volumes at marked and unmarked locations were used to generate a draft set of guidelines, which were reviewed by 30 practicing traffic engineers and highway safety researchers. A final set of guidelines was generated on the basis of that review. The recommended guidelines call for marked crosswalks at all signalized intersections with pedestrian signal heads and unsignalized locations that satisfy specified minimum vehicular and pedestrian volume criteria.

The *Manual on Uniform Traffic Control Devices (MUTCD) (1)* states the primary purposes of crosswalk markings (Section 3B-15):

Crosswalk markings at signalized intersections and across intersection approaches on which traffic stops, serve primarily to guide pedestrians in the proper paths. Crosswalk markings across roadways on which traffic is not controlled by traffic signals or STOP signs, must also serve to warn the motorist of a pedestrian crossing point. At non-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 (*1*, Section 3B-15):

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 continues with a discussion of precautions against indiscriminately using crosswalk markings: "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." Indiscriminate use of crosswalk markings may also result in a reduction in motorist compliance with the law regarding both marked and unmarked crosswalks.

The Uniform Vehicle Code indicates that pedestrians are to have the right-of-way in crosswalks. It states (2, Section 11-502):

When traffic-control signals are not in place or not in operation the driver of a vehicle shall yield the right of way, slowing down or stopping if need be to so yield, to a pedestrian crossing the roadway within a crosswalk. . . .

Most state laws generally follow these guidelines. However, observation indicates that the foregoing priorities are seldom recognized or enforced. Although some areas of the country are reportedly better than others in this regard, there is general recognition that motorist compliance is declining, including yielding to pedestrians.

BACKGROUND

Although there has never been any recognition of more specific guidelines for crosswalk installation at a national level, some states and cities have developed their own. In many localities crosswalk marking is done in response to citizen or political requests or pressure, or both. Often great confidence is placed by the public 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.

In a 1970 study in San Diego (*3*) accident rates at marked and unmarked crosswalks were compared. 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 studied. It was found that the painted crosswalks had 5.7 times more accidents than the unpainted ones. Vehicle and pedestrian volume counts were made for 24 hr at a 10 percent sample of these intersections. It was found that marked crosswalks were used 2.9 times more than unmarked crosswalks. Thus, in terms of use, approximately twice as many pedestrian accidents occur in marked crosswalks than in unmarked crosswalks. However, before condemning marked crosswalks as being hazardous, one must question whether 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 that are using that crosswalk.

For example, one leg of an intersection may have a crosswalk marking because more high-risk pedestrians (very

young or elderly) are using that crosswalk. Similarly, these same pedestrians may go out of their way to use a marked crosswalk, whereas the less cautious adult pedestrian may not do so. The study did, in fact, 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 or destinations, or both (e.g., residences, bus stops, stores, bars). The study also reported differences in time of day and day of the week between marked and unmarked crosswalks. For example, 28 percent of the accidents in marked crosswalks occurred from 5:00 to 7:00 p.m., whereas the unmarked crosswalks had no accidents during that time period. These considerations suggest that there may be more differences between the San Diego marked and unmarked crosswalk locations than the presence or absence of crosswalk markings. If so, the use of the marked and unmarked crosswalk pairs may not be appropriate.

Although the San Diego study is frequently misquoted as having proved that crosswalks are dangerous and should not be used, this is not the case. The report ended with the following statement (3, p. 13):

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, it is apparent that a set of guidelines for their use is sorely needed. These guidelines should be based on research and on the experience of practicing engineers. The guidelines are needed for the following specific reasons:

1. To increase the uniformity of crosswalk application across the country.
2. To 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.
3. To 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.
4. To 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 directly address the safety problem.

PROCEDURE

The goal of this project was to develop a set of guidelines based on current research information that would be accepted and

used by the practicing traffic engineer. In order 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 guidelines were not based on either pedestrian accident occurrence or pedestrian-vehicle conflicts. The draft guidelines were then reviewed by about 30 practitioners and, on the basis of their comments, a final set of guidelines was prepared.

Current Practices

Practicing traffic engineers in nine geographically diverse state and municipal agencies were contacted to determine current operational practices pertaining to the installation of crosswalk markings. Each practitioner was asked specific questions involving

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

It was found that very few of the respondents used specific quantitative procedures for the application of crosswalk markings. All of the respondents marked crosswalks on school routes and most marked crosswalks at signalized intersections. Several of the respondents used "point" warrant systems to rank locations by priority for crosswalk installations. Although three respondents indicated that they considered pedestrian volumes when installing crosswalks, only one quantified the minimum pedestrian volume warrant at 100 pedestrians/day. Most of the respondents believed that factors such as vehicle volumes, pedestrian volumes, vehicle speed, school children, and sight distance should be included in a new crosswalk warrant. At the same time, the practitioners cautioned that the new crosswalk warrants should not require extensive additional data collection.

A literature review was also conducted to identify any existing warrants. Many quantified warrants were found for pedestrian-oriented treatments, such as overpasses, signals, and crosswalk illumination. Only two quantitative threshold warrants for crosswalks were identified. Several localities used a point or priority-ranking system to identify potential crosswalk locations. Some of the existing warrants for various pedestrian-oriented treatments are summarized in Table 1.

Relevant Research

Several other sources of information were used for establishing the initial set of guidelines. The first consisted of data from the study of pedestrian exposure by Tobey et al. (8). 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 part of the analysis involved a comparison of scatter diagrams of pedestrian and vehicular volumes at marked and unmarked crosswalks. It was hypothesized that one would find that crosswalks were marked

TABLE 1 EXISTING WARRANTS FOR VARIOUS PEDESTRIAN-ORIENTED TREATMENTS

	Warrant				
	Crosswalk	Crosswalk	Pedestrian Signals	Crosswalk Illumination	Adult Crossing Guard
Source	Illinois DOT (4)	Toronto (4)	Zegeer et al. (5)	Freedman et al. (6)	Caltrans (7)
Vehicle volume	More than 300 vph for each of any 8 hr of day	Not where turning movements excessive	Fewer than 600 gaps in traffic per hour	Exceeds in three nights: 1,000 vehicles/night (arterial); 500 vehicles/night (collector); 200 vehicles/night (local street)	Exceeds 350 vph in any 2 hr (300 vph if rural)
Pedestrian volume	Exceeds 75 pph for same 8 hr	Exceeds 100 pph in each of 8 hr in which 10 or more wait	Exceeds 60 pph for any 4 hr; 90 pph for any 2 hr; 110 pph for peak hr	50 pedestrians/night (local street or residential); 100 pedestrians/night (all other locations)	40 pph for same hr above (30 pph if rural)
Other	Urban signalized intersection	More than 700 ft to nearest crosswalk; speed less than 40 mph; no sight distance restrictions; four lanes or fewer	None	Three preventable accidents; sight distance considerations; minimum illumination level	More than 600 ft to "safe crossing"

NOTE: vph = vehicles per hour, pph = pedestrians per hour.

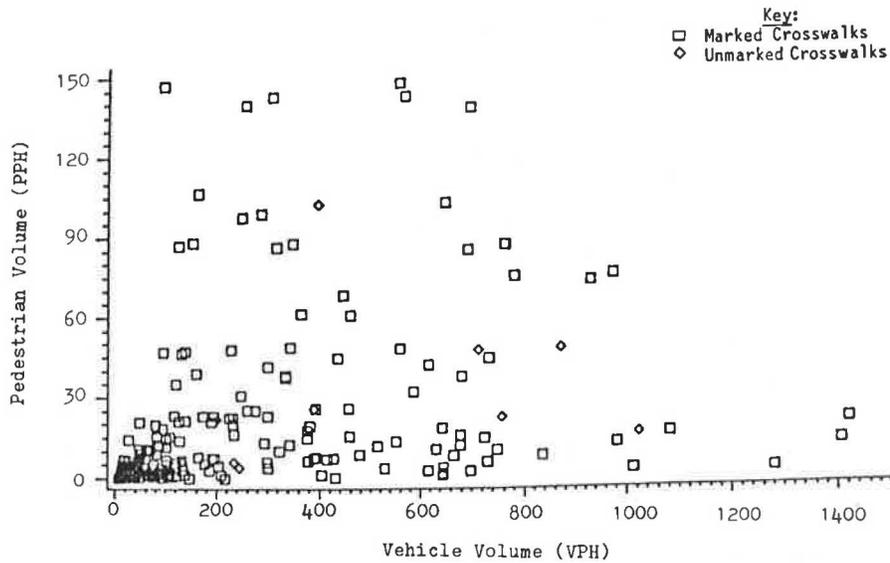


FIGURE 1 Pedestrian and vehicle volumes of marked and unmarked crosswalks at unsignalized local street intersections (8).

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 1 shows the volume distributions for the local street sample.

The data in Figure 1 provide an indication of how practitioners and decision makers have, in the past, determined where crosswalks should be marked. If one makes the assumption that their judgment is 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 would have a minimum vehicular and pedestrian volume and would be convex with respect to the origin. Using this general shape and minimizing alpha and beta error, a basic threshold curve was established that 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.

A second source of information used in establishing the volume threshold curves consisted of existing warrants from outside the United States. Figure 2, prepared for a South African study (9), indicates warrant threshold curves proposed or already in use in Australia, Israel, and South Africa for vehicles and pedestrians at midblock pedestrian crossings. The thresholds are generally higher than those in the suggested guidelines for the United States, which reflects the lower U.S. pedestrian volumes than those abroad. However, the overall philosophy of

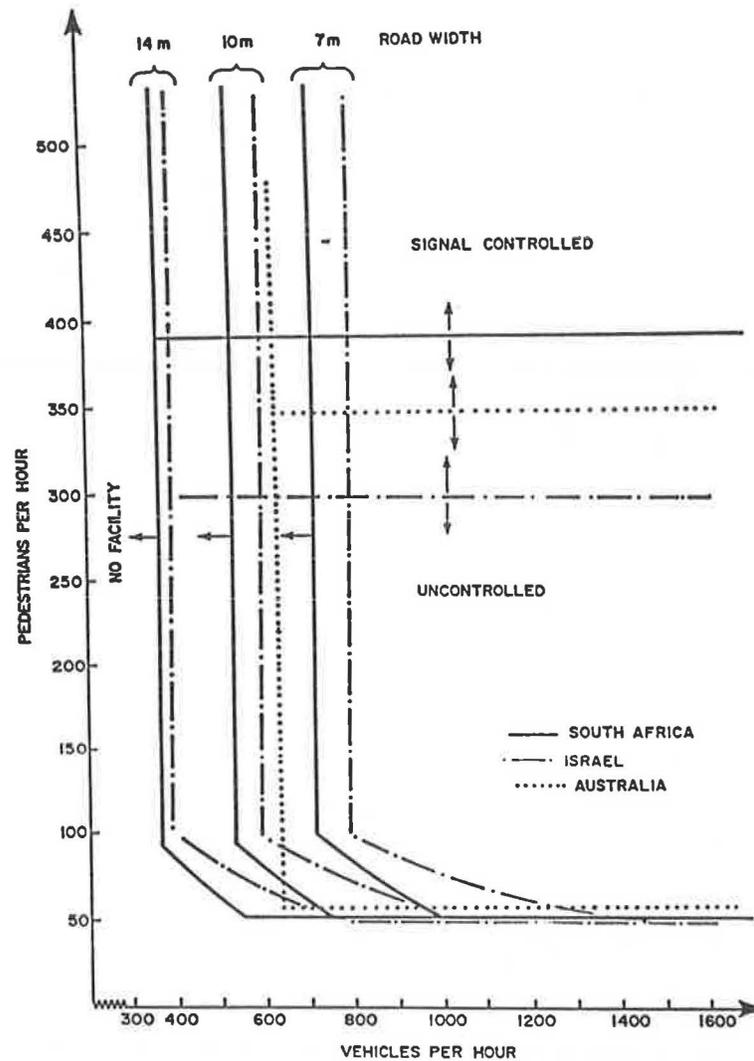


FIGURE 2 Warrants for midblock pedestrian crossings: South Africa, Israel, and Australia (9).

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 were used to generate a preliminary series of warrants for crosswalk markings. Through an iterative process, a draft set of guidelines that was intended to be both responsive to the needs of local practitioners and sensitive to the available research was developed. This draft was sent to 30 practitioners from the engineering and research community for their review. The individuals were selected from the Markings Technical Subcommittee of the National Committee on Traffic Control Devices and the Committee on Pedestrians of the Transportation Research Board.

The review process was believed to be particularly important because the guidelines must pass the test of reasonableness when eventually applied in the field. If their application is overly burdensome or results in the overapplication or underapplication of markings, the guidelines will not become a useful

engineering tool. In addition, there are certain nonquantifiable aspects of crosswalk markings that can only be appreciated by those involved in the application of the guidelines.

The review by practitioners involved sending out the draft guidelines along with a set of questions used to evaluate various aspects. The questions asked were "Are such guidelines needed?" "Will the guidelines benefit state and local agencies?" "Is the format usable?" "Is the concept of a volume-based warrant valid?" "Are the thresholds reasonable?"

Responses by the reviewers were generally positive. There was a consensus that the guidelines were needed, and there appeared to be no major concern with overall approach. Reviewers believed that both the basic criteria and the volume-based thresholds were appropriate. There was some concern over the data collection needs, and this resulted in the inclusion of a peak-hour threshold in addition to the 4-hr threshold in the final set of guidelines. It was also noted that some cities do not mark at any crosswalks at signalized intersections as long as the stop bar is available to provide discipline in vehicle stopping location. This is believed to be an acceptable practice, but markings are still recommended for at least those signalized intersections with pedestrian signal heads. Some reviewers

believed that the guidelines would result in the marking of more crosswalks, whereas others believed that fewer would be marked. The majority, however, thought that the guidelines would result in the marking of about the same number. The comments and suggestions made by the reviewers were considered when the final set of guidelines was prepared.

THE GUIDELINES

The development of a reasonable and succinct set of guidelines required that a set of basic rules or principles be postulated. These basic principles on locating crosswalk markings serve as the foundation for the guidelines:

1. Crosswalks should not be marked where it may be unusually dangerous to cross the street (e.g., locations with high traffic speeds, poor sight distance, or poor illumination).
2. 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 or low pedestrian volume, or both, do not warrant marking. The determination of minimum pedestrian and vehicle volume thresholds is an important part of establishing reasonable guidelines for installation of crosswalk markings.
3. Guidelines for installing crosswalk markings 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 or housing areas for the elderly, or both).

4. 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.

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

6. 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 guidelines were developed on the basis of these principles. The final guidelines for installing crosswalk markings are as follows:

Crosswalk markings should be installed at

- All signalized intersections with pedestrian signal heads. Although it is not necessary to mark crosswalks at all signalized intersections (as long as the stop bar is adequately set back from the intersection), marking crosswalks where pedestrian signal heads are in place reinforces the idea that pedestrians can be expected.
- 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 3 and the following basic criteria:

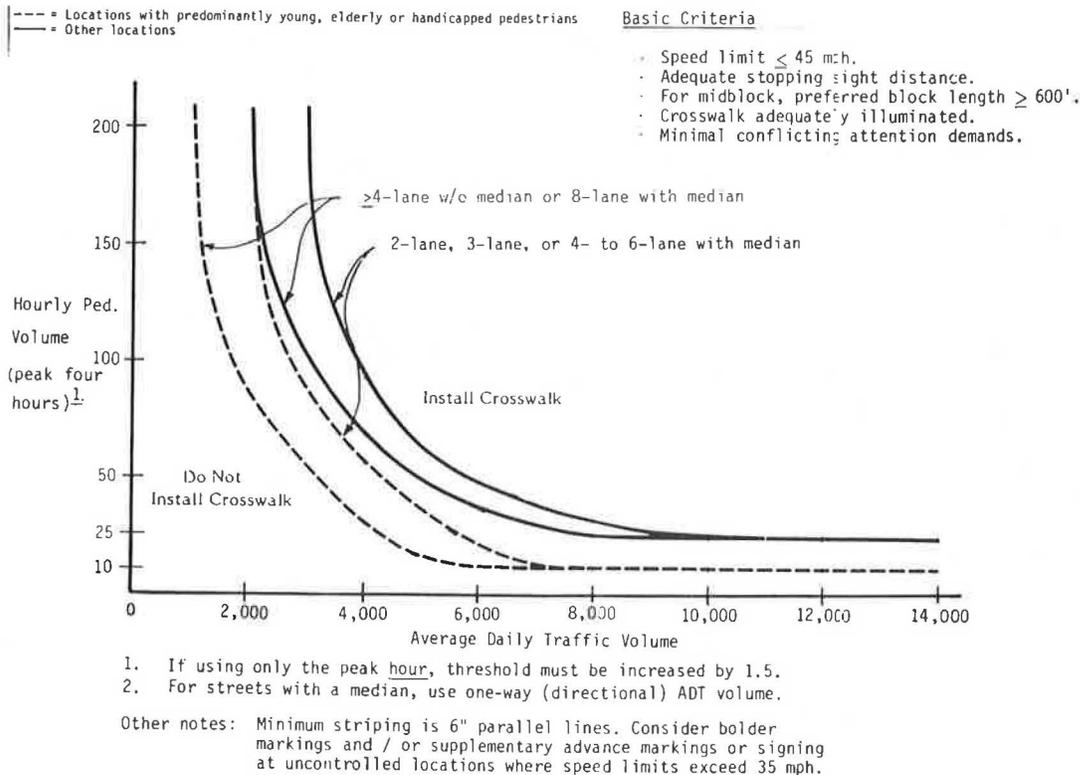


FIGURE 3 Recommended guidelines for installation of crosswalk markings.

- Speed limit ≤ 45 mph
- Adequate stopping sight distance
- For midblock crosswalks, block length of at least 600 ft
- Adequate crosswalk illumination
- Minimal conflicting attention demands

(The last criterion is a judgmental factor suggesting that crosswalks not be marked where complex highway geometrics, signing, or other circumstances distract the driver's attention away from them. Legitimizing such locations as pedestrian crossing points could lead pedestrians into unsafe conditions. Special care should be exercised where drivers tend to look only left to make a right turn or only right to make a left turn, such as at the intersection of one-way streets or at ramp merging areas. Pedestrians should not be encouraged to cross in areas where the driver does not already scan for vehicular traffic.) As long as the basic criteria governing sight distance, speed limit, and so on, are met, a crosswalk marking is deemed appropriate if the pedestrian and vehicular volumes place it above the appropriate curve in Figure 3. Each crosswalk is analyzed by approach leg, indicating that a crosswalk marking might be warranted on one side of an intersection and not on the other. Thus the guidelines might suggest that only one crosswalk need be marked at a given intersection. If each approach warranted a crosswalk marking, then all would be marked. However, one should consider marking both crosswalks on a given roadway if the presence of only one would suggest to pedestrians that they make an unnecessary, hazardous crossing to get to it.

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

These guidelines represent a melding of the philosophies found in foreign and domestic practice. The most important elements of the guidelines are the basic criteria, which place some restrictions on crosswalk-marking applications to prevent their being placed in locations that would be extremely hazardous to the pedestrian. Placing crosswalk markings in locations with high speeds or poor sight distance is never advisable. A crosswalk marking is not a solution to such situations, and other preventive measures should be considered.

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

The volume thresholds are reduced for locations where the young, elderly, or handicapped make up 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 mph, the guidelines suggest the placement of markings bolder than the standard 6-in. parallel lines, such as longitudinal (zebra) stripes. Supplemental

crosswalk signs should be considered for crossings at uncontrolled intersection legs and midblock where the crossing is in a high-speed or potentially hazardous location.

DISCUSSION OF RESULTS

Another element of the evaluation involved a comparison of the pedestrian volume thresholds with other related warrants and criteria. A new pedestrian warrant for the installation of traffic signals was recently approved by the National Committee on Uniform Traffic Control Devices. The new warrant is based on an FHWA study and suggests a minimum pedestrian volume of 100 pedestrians per hour (pph) for 4 hr.

The current minimum volume requirements in the MUTCD for warranting a traffic signal are 150 pph in the same hours for which the peak 8 hr of vehicular volume occur. The new lower pedestrian volume threshold will make it easier to justify a signal on the basis of pedestrian volume. Justifying a signal on the basis of pedestrian volume would still be rare, however.

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 that 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 for pedestrians and informing them of proper crossing locations.

One of the major concerns in pedestrian safety is the general lack of respect by drivers for 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 mechanisms 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 are needed in the marking of crosswalks. The proposed guidelines should help to accomplish this objective.

ACKNOWLEDGMENT

This paper describes part of the results of a research project sponsored by FHWA.

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DISCUSSION

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In August 1970 the city of San Diego published the results of a research project entitled Pedestrian Crosswalk Study—Accidents in Painted and Unpainted Crosswalks (1). In brief, the 5-year study encompassed 400 intersections, each having one marked and one unmarked crosswalk across a main thoroughfare and uncontrolled by signals or school crossing guards. The study showed “in terms of usage” that about twice as many pedestrians were hit in the marked crosswalks as in the unmarked crosswalks. The elderly and young showed their usual high involvement pattern in both marked and unmarked crosswalks. More striking was the accident experience of those pedestrians in the 25 to 44 age group, who had no accidents in the unmarked crosswalks but were involved in 25 accidents in the marked crosswalks. As a result of this study, San Diego revised its crosswalk warrants in 1970 (2). Since that time, many jurisdictions have indicated interest in the San Diego study and its revised warrants and guidelines. More recently, Smith and Knoblauch undertook to develop guidelines that might be adopted nationally to facilitate installation of marked crosswalks on a uniform basis. I would like to support them in their efforts. Many of their criteria are an outgrowth of the San Diego findings and warrants. Based on these similarities and the 16 years of experience with these warrants, this discussion is being conducted to point out the rationale for some of the basic criteria shared in common and, it is hoped, to provide constructive comments on improving the proposed guidelines.

SHARED CRITERIA

When San Diego modified its crosswalk warrants in 1970 (2), several basic criteria for installing marked crosswalks were recognized.

Pedestrian Volume

Crosswalks will not be installed where the pedestrian volume is less than 10 pph during the peak pedestrian hour.

Rationale: There should be sufficient minimal pedestrian usage to warrant the installation of the markings and to provide credibility to the motorist that pedestrians indeed use the crosswalk (3).

Approach Speed

Crosswalks will not be installed on roadways where the 85th-percentile approach speeds are in excess of 45 mph.

Rationale: Analysis and field studies show that at speeds above 45 mph, crosswalk markings are indiscernible by approaching motorists. Therefore, motorists at these speeds might not be able to see, react, and come to a safe stop in time to avoid a collision with a pedestrian (4).

Visibility

Crosswalks will not be installed unless the motorist has an unrestricted view of all pedestrians at the proposed crosswalk site for a distance not less than 200 ft approaching from each direction. Sites with grades, curves, and other sight-restrictive features will require special attention.

Rationale: Again, analysis and field studies show that unless given sufficient time and space to see and react to the presence of a pedestrian, the motorist may not be able to stop in time to avoid a collision (4). A conservative stopping distance of 200 ft was employed to provide for errant motorists traveling at speeds in the range of 45 to 50 mph.

Illumination

The proposed crosswalk site must have adequate lighting in existence or scheduled for installation before the installation of the crosswalk.

Rationale: A special analysis of pedestrian-vehicle collision courses during nighttime accidents suggested that the low beams of automobiles, which are often used in urban areas, may not be sufficient to illuminate the pedestrian in time to avoid a collision (4). Therefore, if a marked crosswalk is installed, it is important that the jurisdiction provide adequate crosswalk lighting.

DIFFERENCES

It is interesting to see that Smith and Knoblauch have also incorporated the foregoing requirements into their guidelines, with two minor exceptions:

1. The minimum peak pedestrian volume has been increased from 10 to 25 pph, except where young, elderly, or handicapped pedestrians need to cross (in which case they provide for 10 pph). This higher figure may make certain crossings more difficult to qualify for marked crosswalks.
2. A basic criterion (Figure 3), “minimal conflicting attention demands,” has been added, which may be a valid consideration. But in this set of guidelines, it is not adequately

explained what it means or how this criterion is to be applied. Presumably, if there are other features or characteristics in the vicinity of the crosswalk that might divert the motorist's attention away from the pedestrian, this would be sufficient reason for not installing a marked crosswalk. Unfortunately, in the urban setting, there are many things competing for the motorist's attention. Furthermore, what guarantee is there, after a marked crosswalk has been installed, that someone might not install an attention-getting animated sign?

There are several other similarities and differences between the San Diego 1970 warrants and Smith and Knoblauch's 1987 guidelines that merit examination.

Point System

In addition to the basic warrants, San Diego employs a point system requiring 16 out of 28 possible points to qualify for the installation of a marked crosswalk. These points are obtainable under three categories.

Pedestrian Volume

Pedestrian volume ranges from 2 points for 11 pedestrians crossing per peak hour to 10 points for over 100 pedestrians crossing per peak hour.

General Conditions

Up to 8 points are provided for improved channelization considerations. It should be emphasized that San Diego tends to place considerable stress on the role of the crosswalk as a channelization device rather than as a safety device per se.

Gap Time

The warrant for gap time provides for up to 10 points based on the average number of safe gaps per 5-min period available to permit the pedestrian to cross the street without being in conflict with a vehicle. Ideally, a pedestrian should not have to wait more than 1 min for there to be a safe gap in traffic to cross from one side of the street to the other or to cross to the center median. The rationale behind this warrant is that if a pedestrian has one or more safe gaps each minute to cross a street, it may not be as necessary to have a marked crosswalk. On the other hand, as traffic increases or the width of the street increases, there become fewer and fewer safe gaps available. In that case, the marked crosswalks may (provided other conditions are favorable) help the pedestrian communicate his need and right to cross the street. To some, this rationale may seem paradoxical, that is, some may ask, "If the vehicular volume is higher or if the street is wider, then isn't the exposure greater?" So it would seem, but as the various San Diego studies indicated in the original report, exposure is not the sole factor determining whether a pedestrian is at risk. What appears to be more important is the pedestrian's ability to assess the risk and his willingness to accept the risk. The San Diego data seemed to indicate that on narrower streets or streets where vehicular volumes were low, although the exposure was lower, the "risk-

taking behavior" in marked crosswalks tended to be greater (1). This would tend to indicate that jurisdictions might be better off not to install marked crosswalks if such markings might tend to reinforce aggressive pedestrian behavior or inflate a pedestrian's false sense of security. In such cases, not installing a marked crosswalk might tend to make the pedestrian more apprehensive and more alert to approaching vehicles and thereby avoid collisions. By contrast, as street widths and vehicular volumes increase, the exposure increases. But, more importantly, the risk-taking behavior in marked crosswalks tends to be lower. This may be due to the fact that the exposure and potential risks are more evident to the pedestrian. Thus, despite the presence of the markings, pedestrians tend to be more careful in crossing the street. Similarly, the gap-time concept takes both exposure (in terms of width and vehicle volume) and relative pedestrian risk-taking behavior into account. In other words, the greater the apparent exposure, the greater the likelihood that the pedestrian will exercise appropriate caution in crossing the street and will tend less to misuse a marked crosswalk. This rationale is not only one of the features of the 1970 San Diego warrants, but also of Smith and Knoblauch in their proposed guidelines.

Nomograph

The guidelines of Smith and Knoblauch differ primarily from the San Diego warrants in that, although they utilize the same basic warrants as San Diego (approach speed, visibility, illumination) instead of using a supplementary point system, they use a supplementary nomograph. The general concept of a nomograph is good. Some of their basic values appear to be reasonable. However, one must be careful with both a point system and a nomograph system in recognizing that the cut-off points or, in the case of the nomograph, the demarcation or decision line is not always as clearly defined as it may seem. Rather than a sharp line there is a blurred zone where conditions could go either way. Thus, when warrants or guidelines are applied, good engineering judgment based on experience and knowledge of the site are important aspects of the decision-making process. I recognize that Smith and Knoblauch have tried to simplify the decision-making process by utilizing "number of lanes" as a basis for their family of decision lines. But I must admit that ignoring the actual street width and pedestrian crossing time bothers me somewhat; that is, a narrow two-lane street is handled the same as a wide two-lane street and a six-lane street is handled the same as a four-lane street. Also, how does one handle a three-lane one-way street? The purpose of these comments is not to nitpick, but rather to point out some important deficiencies that need to be addressed.

Traffic Signals and School Crossings

Smith and Knoblauch have attempted to create a universal set of guidelines for installing marked crosswalks at traffic signals and school crossings. In some respects this effort appears commendable, but from a practical viewpoint it may be counterproductive. Crosswalks at traffic signals and school crossings function differently than crosswalks on uncontrolled thoroughfares. At signalized locations or school crosswalks,

pedestrian movements are controlled by the traffic signal or the crossing guard rather than the crosswalk markings. Similarly, motorists' behavior is influenced to a much greater degree by the presence of a traffic signal or crossing guard than it is by the presence of crosswalk markings (although marked school crossings are an important and integral part of the school crossing program). My comment on these two items is not intended to ignore markings at signals or school crossings but rather to point out that they deserve more thought and space than three brief lines. If we say that all signals with pedestrian signal heads should be marked, does that mean that signalized intersections without pedestrian heads should not be marked? And is really necessary to mark all crosswalks where there are pedestrian signal heads? As a matter of fact, most of San Diego's traffic signals in its downtown area, and elsewhere, have had only a marked limit line without marked crosswalks for over 30 years and have functioned very well. Even so, the city recognizes that there are places where the geometrics are such (wide intersections, skew orientation, etc.) that marked crosswalks are both desirable and necessary. Conversely, there are other places, such as on one-way street systems, where the stop bars provide a useful supplemental warning to keep motorists from entering a one-way street in the wrong direction. In these cases, marked crosswalks on all legs with pedestrian heads may confuse the motorist without appreciably improving either the mobility or safety of a pedestrian.

Regarding the criteria for midblock crosswalks, in all fairness, I would say that both the San Diego warrants and the Smith-Knoblauch guidelines need better definition in terms of evaluating pedestrian use, and why, where, when, and how midblock crosswalks should be installed. Many jurisdictions would rather not use midblock crosswalks at all. But there are valid conditions for installing and utilizing marked midblock crosswalks in a safe and efficient manner (5).

CONCLUSIONS AND RECOMMENDATIONS

Although San Diego's crosswalk warrants have served the city well for 16 years, San Diego does not claim to have the ultimate set of warrants. There are features in the San Diego warrants that need to be clarified and revised, particularly those involving midblock crosswalks. Similarly, Smith and Knoblauch's guidelines need further review and improvement. Several tests for good traffic warrants are the following:

1. Will the proposed installation produce the desired results in terms of safety and mobility for both the pedestrians and the drivers?
2. Will the proposed installation have credibility to and acceptance and compliance by the users (pedestrians and drivers)?
3. Are the warrants easy to understand and easy to apply by the agency's staff under all conditions?

With regard to the first two items, it is recommended that the guidelines be applied in a real-world situation in several cities and monitored in some appropriate controlled test to determine how they affect safety, mobility, and compliance.

With regard to the third item, it appears that the total evaluation time for the Smith-Knoblauch guidelines would be 4 hr for the pedestrian vehicle counts plus 30 min supplementary field and preparation time, 1 hr driving time to and from the site, and 1 hr office time, for a total of 6.5 hr for each evaluation. By comparison the city of San Diego's present warrants require 1 hr for the pedestrian gap study and pedestrian volume count plus 30 min supplementary field and preparation time, 1 hr driving time to and from the site and 1 hr office time, for a total of 3.5 hr for each evaluation. This is a saving of 3 hr per location over the Smith-Knoblauch evaluation procedure. This suggests that Smith and Knoblauch might wish to reassess their evaluation procedures to see whether they can be made more cost-effective. Other recommendations from the earlier commentary include the following:

- The basic criteria listed on the nomograph (Figure 3) including speed, stopping sight distance, illumination, and midblock length, appear to be valid, but perhaps unduly brief. It is suggested that an accompanying supplementary description be provided, especially concerning midblock crosswalk installations.
- The basic criterion "minimal conflicting attention demands" is too ambiguous and subject to potential litigation problems. It is recommended that it be either clarified or dropped.
- The nomograph evaluation is a good one. However, decision curves on the nomograph should reflect street width rather than number of lanes. This would eliminate the ambiguity of what to do with one-way streets or three-lane streets or six-lane streets, and so on. Streets with a median would be handled on the basis of the widest portion from curb to median.
- If my recommendation for utilizing a family of decision curves based on width rather than number of lanes is adopted, then I realize that the nomograph could become quite "busy." In this case, it may be desirable to develop a second nomograph with a new family of curves to handle the needs of the young, elderly, and disabled. Similarly, appropriate criteria must be developed to define when a jurisdiction should utilize the second set of curves (e.g., any combination of 10 children, seniors, or handicapped crossing per hour?).
- Consideration might be given to installing marked crosswalks on an "exception" basis for those special cases in which they are needed by partially sighted persons for guidance across certain intersections. Such crosswalks must not be installed indiscriminately, but in close consultation with appropriate experts such as specialists in orientation and mobility for the blind.
- If I understand their report correctly, Smith and Knoblauch, unlike the city of San Diego, do exempt "crosswalks used to clarify the preferred crossing location" from their other evaluation procedures, including the basic criteria and the nomograph evaluation. I can see certain advantages in exempting such channelization devices from either a point or nomograph evaluation, but they should definitely pass the basic criteria warrants on approach speed, visibility, and illumination. If not, they could become potential safety hazards.
- Although neither the San Diego warrants nor the Smith and Knoblauch guidelines provide for it, there appears to be

some advantage in providing a certain latitude to cover "unusual conditions" or what is sometimes referred to as "engineering judgment." The conditions cited in the two previous recommendations are cases in point. This is where a point system as opposed to a nomograph evaluation may have certain advantages.

- The criteria for marked crosswalks at either signalized intersections or school crossings should be handled separately. It is recommended, in order to do them justice, that they be deleted from this set of guidelines and appropriate guidelines be developed for each in accordance with its own unique problems and needs. Those who take on the job of preparing these supplementary warrants will, it is hoped, avoid jumping prematurely into quantitative assignments or threshold levels and ask themselves the basic question: Do marked crosswalks benefit the pedestrian at a standard signalized intersection, and if so, how? They may find that, with the exception of complex or wide intersections, pedestrians rely little or not at all on the marked crosswalks at signals.

- Finally, it is recommended that in addition to engineering and enforcement considerations, attention continue to be directed to educating pedestrians of all ages regarding what the marked crosswalk can and cannot do and to caution them to be just as careful in using a marked crosswalk as they are when using an unmarked crosswalk.

Smith and Knoblauch are to be commended in their efforts to develop a uniform set of guidelines for marked crosswalks. It is hoped that the comments and recommendations offered in this discussion and by others will help them to successfully achieve their goal in developing an improved, rational, and effective set of crosswalk guidelines that will enhance safety and mobility for the pedestrian and other road users.

REFERENCES

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AUTHORS' CLOSURE

We appreciate the comments of Herms, particularly his practical perspective on an issue to which there are no absolute answers. Unfortunately, research provides less guidance than most people think on the question of whether crosswalk markings add to or detract from the safety of pedestrian crossings. Thus, we are left with the dilemma of wanting to provide information to both pedestrians and drivers that might help

their decision-making process, but not having the firm research data to say with authority exactly how markings ought to be applied. Overlaid on this is the need to wisely allocate financial, staff, and material resources of local, state, and federal governments. Placing crosswalks everywhere is neither financially nor functionally sound. It is true with virtually any traffic control device that the more of them there are, the less they are respected. This would certainly be true of crosswalk markings. Thus, there must be some criteria for controlling where these traffic control devices are placed.

In retrospect, the attempt to devise a useful set of criteria for crosswalk markings was as much an effort to describe where they should not be placed as where they should be placed. In effect, the criteria are a checklist for what should be looked for in deciding whether to accept or reject a candidate crosswalk marking location, with thresholds placed on some of the criteria to provide consistency from one jurisdiction to the next or within a single jurisdiction.

Unless history proves otherwise, we strongly suspect that our suggested guidelines are not perfect. They heavily incorporate engineering judgment, both our own and that of engineers from around the country who, for one reason or another, marked crosswalks that ended up as data points on our graphs. Even if a massive before-and-after safety study (with control group) of crosswalks were to be conducted, we would still need to rely to a great degree on engineering judgment for factors that one should consider in marking a crosswalk; and because engineering judgment is involved, there will undoubtedly be philosophical differences in the way these guidelines are approached.

One of the philosophical differences between our suggested guidelines and those developed in San Diego is the point system versus a nomograph-threshold approach, as suggested here. Although point systems have been widely used in the transportation industry, we believe that they introduce a temptation for the engineer to be more lax in thinking through all the factors that should be considered. They can more easily become a cookbook approach than will a nomograph-threshold approach. True, a point system can bring all those important factors into consideration, but it becomes too easy for the engineer to be removed from personally thinking through the pros and cons of each situation and there is no assurance that the weights assigned in the point system reflect what are the most important factors. We should also caution that just because a location passes the minimum volume thresholds in our nomograph system, it does not mean that a crosswalk is automatically warranted. There are, as Herms states, transitional areas that could be decided either way, depending on other factors.

The determination of whether to use street width itself or number of lanes could be reasoned either way, as long as the guidelines cover every possible combination. We selected number of lanes because it is simply stated and reflects the basic idea that wider streets are more difficult to cross, implying that crosswalk markings would therefore be more necessary. We think that people will instinctively translate feet into lanes and that it is better to provide them with lanes in the first place. In addition, using feet would also require subtracting out the width of parking lanes. The suggested guidelines consider lanes of moving traffic. If a parking lane is used for travel at any time during the day, it should be considered a travel lane.

Hermes brings up a good point concerning the marking of signalized intersections. It should be a separate issue from crossings of uncontrolled intersection legs. Our rationale for suggesting markings at locations with pedestrian signal heads is based on the thought that if an investment has been made in the signal heads, the marking of a crosswalk involves a relatively small additional investment. In addition, the fact that a pedestrian signal is there usually means that there is at least some pedestrian volume warranting it. However, we do not take a strong stand that there must be crosswalk markings at all such locations. As long as the stop bar is adequately set back from the intersection, it should be clear enough, it is hoped, that this is the pedestrian's legitimate crossing area. Local policy should govern, but we believe that economics still dictates that the high-pedestrian-volume locations should be considered, even at signalized intersections. The addition of crosswalk markings can make the intersection as a whole more conspicuous and prominent, which may have some influence on driver sensitivity toward pedestrians as a side benefit.

There are several factors in the original paper that need clarification. The inclusion of the "minimal conflicting attention demands" criterion was an effort to recognize that the pedestrian can sometimes become lost to the driver's view on roads with cluttered visual backgrounds and complex maneuvering requirements. Although it is difficult to quantify these situations, it is a factor that should be included on the engineer's checklist when a particular situation is being evaluated. We have seen areas that could satisfy the other criteria at which we would not install a crosswalk because the driver was

already being asked to do too much without having to watch out for pedestrians. One location to be particularly aware of is merging areas, where drivers must be looking backward to check for traffic merging from the right or left. Adequate illumination is also a critical and often-neglected element of consideration, but it is difficult to quantify. Ideally, crosswalk marking locations should be checked at night to determine how well the criterion is met, but the decision ultimately rests with the judgment of the engineer.

Separate nomographs for locations with young and elderly pedestrians would undoubtedly make the guidelines easier to apply for those groups. Likewise, volume thresholds could certainly be varied among or within urban areas. What may be appropriate in a dense urban area may not be appropriate in a small town. These are refinements that users of the overall framework should feel free to test.

Perhaps the word "framework" is the best way to describe our suggested crosswalk-marking guidelines. It is a way of logically addressing an often controversial and even political issue. We would not want the guidelines viewed as a black box, but at the same time we believe that they, or some future variation of them, will provide some assistance in making choices that must be made by someone. We also hope that the guidelines will be tried, modified, and improved, and we agree that the understanding of crosswalk markings by the general public is sadly lacking and would encourage additional efforts in that area as well.

Publication of this paper sponsored by Committee on Pedestrians.