Guidelines for Marked and Unmarked Pedestrian Crosswalks at Unsignalized Intersections

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ABSTRACT

There have been controversial perceptions with respect to the use of marked pedestrian crosswalks at unsignalized intersections over the years. Several agencies tend to prefer marked crosswalks at most intersections with the expectation of improving pedestrian mobility and safety. However, several studies concluded that marked crosswalks actually involve higher pedestrian accident rates than unmarked crosswalks. Such controversial results make it difficult for states and local agencies to develop policies pertaining to pedestrian crosswalks. Existing guidelines for determining crosswalk type are normally presented in a flowchart format or documented as a point system. One of the major issues of the existing guidelines lies in the lack of comprehensive consideration and interpretation of all potential variables. A new guideline for determining pedestrian crosswalk types is proposed in this study. The guideline is based on a combination of PROMETHEE and Analytical Hierarchy Process multi-criteria decision analysis methodologies. A ranking score considering all the potential factors, including variables such as volume, speed limit and pedestrian related crash records is produced to represent the likelihood of using a certain type of crosswalk. Furthermore, the proposed guideline was applied to a case study involving 25 unsignalized intersections in the City of Reno and City of Henderson in the State of Nevada.

Key Words: Pedestrian Crosswalks; Marked and Unmarked; Unsignalized Intersections; Multi-criteria Decision Analysis; PROMETHEE and Analytical Hierarchy Process Methodologies.

1 INTRODUCTION

The original intention of marking the crosswalks is to guide pedestrians and also reduce the potential conflicts of vehicles and pedestrians. However, over the past several decades, there have been controversial perceptions and study results concerning the performance of marked and unmarked crosswalks at unsignalized intersections that challenged this elementary purpose (*1*, *2*, *3*, *4*, *5*). Over the years, studies conducted in the United States and overseas countries have advanced several guidelines helping government decide under what conditions a marked pedestrian crosswalk would be a better choice.

The widely used national guideline regarding crosswalk marking is documented in the Manual on Uniform Traffic Control Devices (MUTCD) Section 3B-17 and 3B-18 (*6*). It states that crosswalks should be marked at all intersections where there is substantial conflict between vehicular and pedestrian movements. This guideline lacks further quantitative criterion with respect to these factors. A complement of foregoing general guidelines put forward by Zegeer et al. in 2005 for the Federal Highway Administration (FHWA) divided crosswalks into three possible ratings: (1) candidate sites for marked crosswalks (i.e. marked crosswalks must be installed carefully and selectively.); (2) probable increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements; (3) marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks. (*7*). Basically, these guidelines consider three factors speed limit, vehicle ADT and number of travel lanes comprehensively. Even though pedestrian crash is mentioned, the actual procedure ignored the number of pedestrian-related crash record factor. This guideline indeed points out that determining a pedestrian crosswalk type belongs to the multi-criteria analysis territory.

In the State of Nevada, several agencies are currently executing internal crosswalk marking guidelines according to their own situations. A statewide agency survey was conducted to gather information regarding current practices. Clark County uses 20 pedestrians per hour as the determination to install a marked crosswalk. City of Las Vegas follows the general guideline outlined in the MUTCD while City of Henderson is applying the FHWA guideline. Besides those relative mature guidelines, other agencies do not have a specific principle when it comes to pedestrian crosswalks. Therefore, most agencies indicated that statewide guideline would be helpful for promoting uniformity in application of pedestrian crosswalk markings. The existing guidelines are either qualitative statement or mostly relying on single dominate factor like pedestrian volume. Such guidelines lack a balanced consideration of all the potential factors. Since those potential impact factors have different categories and criteria, the crosswalk type decision making process can be considered as a typical multi-criteria analysis problem. Accordingly, the perplexed nature of the crosswalk issue can be understood comprehensively. This study applies a revised multi-criteria analysis methodology to develop a new guideline to assist engineer to decide pedestrian crosswalk type.

2 MULTI-CRITERIA METHODOLOGY

2.1 Multi-criteria Decision Analysis

A multi-criteria decision problem can be described as a decision making problem with *m* criteria and n alternatives, and let $C_1, C_2 \cdots C_m$ and $A_1, A_2 \cdots A_n$ denote the criteria and alternatives, respectively (*8*). A standard feature of a multi-criteria decision making methodology is the decision matrix as shown in Equation (1). The score x_{ij} describes the performance of alternative A_j against criterion C_i. The global ranking value is then calculated as the product of weight and scores.

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

In the decision matrix, weights $\{w_1, w_2, \cdots w_m\}$ are assigned to the criteria. Weight w_i reflects the relative importance of criteria C_i to the decision, and is assumed to be positive. The weight can be obtained separately using Analytic Hierarchy Process (AHP) (*9*) method. The overall performance of each alternative is obtained by Equation (2). A wide range of multi-criteria decision analysis methods, such as AHP approach (*9*), Simple Additive Weighting Method (*10*), TOPSIS Method (*11*), Outranking Methods (*11*) can be applied to achieve a final ranking or scoring for the decision alternatives (*12*). Considering maneuverability and practical applicability, a developed guideline following PROMETHEE methods, a member of outranking methods, is proposed seeing mark and unmark as two alternatives in this study.

$F(A_j) = \sum_{i=1}^{m} w_i\, r_{ij}$, where r_{ij} is the normalized performance rating of alternative A_j against criterion C_i. (2)

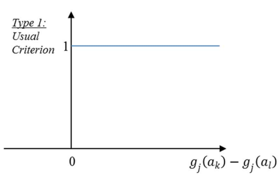
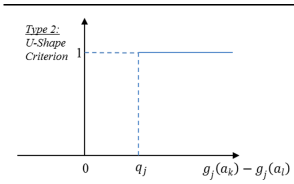
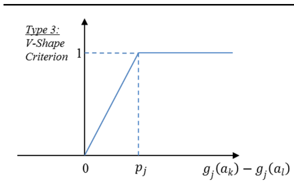
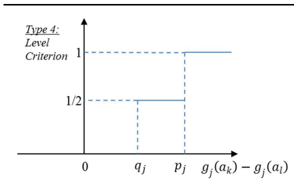
2.2 PROMETHEE Methodology

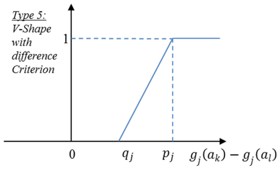
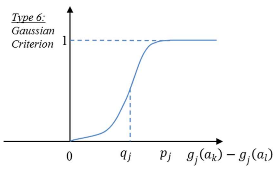
PROMETHEE methodology is a well-known for solving complex choice problems with multiple criteria and multiple participants (*13*). The preference structure in this methodology is based on pair wise comparisons. The deviance between the evaluations of alternatives on a particular criterion is considered. For small deviations, the decision-maker will allocate a small preference to the best alternative and even possibly no preference if it is considered that this deviation is negligible (*14*). The outranking degree $\prod(a_{k,}a_l)$ describes the credibility of the outranking relation that alternative a_k is better than alternative a_l. For each pair of alternative $(a_{k,}a_l)$, it is calculated using Equation (3).

$\prod(a_{k,}a_l) = \sum_{j=1}^{n} w_j F_j\,(a_{k,}a_l)$, where $F_j(a_{k,}a_l)$ is preference function, w_j is the weight. (3)

In contrast to using normalized subjective rating scores as Equation (2), PROMETHEE methodology uses a pre-defined preference function in Table 1 to pair wise compare the global performance of alternatives under different criteria. The value $F_j(a_{k,}a_l)$ for a pair of alternative a_k and a_l regarding criteria C_j is calculated using either one of the functions.

Table 1 Preference Functions in PROMETHEE Methodology *(11)*

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

	$F_j(a_{k,}a_l) = \begin{cases} 1, & if\ g_j(a_k) - g_j(a_l) \geq p_j \\ 0, & if\ g_j(a_k) - g_j(a_l) \leq q_j \\ \dfrac{g_j(a_k) - g_j(a_l) - q_j}{p_j - q_j}, & otherwise \end{cases}$	q, p
	$F_j(a_{k,}a_l) = \begin{cases} 0, & if\ g_j(a_k) - g_j(a_l) \leq 0 \\ 1 - e^{-\frac{(g_j(a_k) - g_j(a_l))^2}{2S^2}}, & if\ g_j(a_k) - g_j(a_l) > 0 \end{cases}$	s

3 PROPOSED GUIDELINE

In accordance with discussions above, determining a pedestrian crosswalk type is a typical multi-criteria decision problem involving alternatives Mark and Unmark as well as several multi-criteria decisive variables. The essential conceptual guideline theory is,

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

In this definition, the *Function* can be defined as linear or non-linear according to the nature of correlation between response Mark/Unmark and explanatory factors like volume, speed limit, and intersection geometry demonstrated as $\left[\lambda_i^x + \lambda_j^y + \cdots + \lambda_k^z, i = 1,2, \cdots I; j = 1,2, \cdots J; k = 1,2, \cdots K\right]$. The primary goal is to attain a decision through the combination of all possible factors simultaneously. The proposed guideline comprises three subsections, Input Multi-Criteria Description as an input interface, Calculation Procedure containing inner analysis of response and explanatory factors, and the ultimate Output Results providing the final preference decision. The model structure is demonstrated in Figure 1. The principles and implementations of proposed guideline are discussed below.

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

The explanatory factors were obtained from previous literature and a comprehensive statewide agency survey within seven jurisdictions in Nevada State. A survey questionnaire was sent to the seven agencies in Nevada in March 2011. Feedbacks were received in April and May. Typical questions were asked about the factors, criteria and their degree of importance that should be considered in developing guidelines for marked crosswalks at unsignalized intersections. Most of the responses claim that the pedestrian volume and speed limit are the major factors followed by the crash record and number of travel lanes. Also, some engineers agree that the policy preference tendency regarding pedestrian crosswalks may be different for different jurisdictions. Therefore, a policy preference factor should also be included in the guideline.

As a result, ten factors were identified including Policy Preference Tendency (PPT), Geometry Layout of Intersection (GL), Pedestrian Accident Occurrence (PRC), Median Type (MT), Number of Travel Lanes (NTL), Vehicle Speed Limit (SL), Pedestrian Volumes (PV), Traffic Volumes (TV), Available Gaps (AG) and Distance to Nearby Crosswalk (DNC) in the very first input interface section.

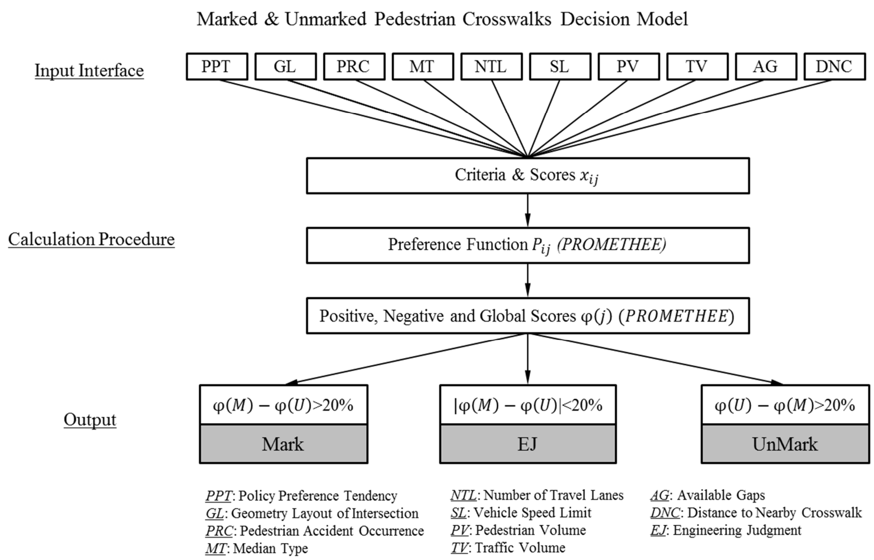


Figure 1 Flow Chart of Proposed Guideline

Those ten variables and their scores g_{ij} to different criteria under mark versus unmark circumstances are generated and therefore the decision matrix is formed as well in Table 2. Each factor was scored a value between 0 and 10. For the sake of simplicity, the assumption is made that higher score value means better preference for alternatives. In practice, a score 10 suggests that a certain type of crosswalk is absolutely needed. The factor policy preference tendency is considered at the first place. Three categories are given to this factor as 1-Conservative, 2-Moderate and 3-Aggressive. The conservative policy preference tendency means marking is a preferred choice in this study since it satisfies the ground needs to guide pedestrians. On the contrary, the aggressive tendency indicates that unmark is a preferred choice because it is believed that marking is not necessary at the study site.

Table 2 Factors Criteria and Scores

PPT	*1*	*2*	*3*	*GL*	*4-Leg*	*3-Leg*			
M	10.00	5.00	0.00	M	6.42	7.42			
U	0.00	5.00	10.00	U	3.58	2.58			
M-U	10.00	0.00	-10.00	M-U	2.84	4.84			
U-M	-10.00	0.00	10.00	U-M	-2.84	-4.84			
MT	*No*	*Yes*	*NTL*	*6*	*5*	*4*	*3*	*2*	*1*
M	7.30	2.70	M	9.00	8.56	7.63	7.12	2.88	2.50
U	2.70	7.30	U	1.00	1.44	2.37	2.88	7.12	7.50
M-U	4.60	-4.60	M-U	8.00	7.12	5.26	4.24	-4.24	-5.00
U-M	-4.60	4.60	U-M	-8.00	-7.12	-5.26	-4.24	4.24	5.00
PRC	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
M	9.50	9.50	8.50	8.00	7.75	7.30	6.75	5.00	2.75
U	0.50	0.50	1.50	2.00	2.25	2.70	3.25	5.00	7.25
M-U	9.00	9.00	7.00	6.00	5.50	4.60	3.50	0.00	-4.50
U-M	-9.00	-9.00	-7.00	-6.00	-5.50	-4.60	-3.50	0.00	4.50
SL	*55*	*45*	*35*	*25*	*15*				
M	0.00	0.00	5.00	7.99	8.50				
U	10.00	10.00	5.00	2.01	1.50				
M-U	-10.00	-10.00	0.00	5.98	7.00				
U-M	10.00	10.00	0.00	-5.98	-7.00				
PV	*40+*	*40*	*30*	*25*	*20*	*15*	*10*	*5*	
M	9.25	8.85	8.50	7.58	7.25	3.00	2.75	1.50	

U	0.75	1.15	1.50	2.42	2.75	7.00	7.25	8.50
M-U	8.50	7.70	7.00	5.16	4.50	-4.00	-4.50	-7.00
U-M	-8.50	-7.70	-7.00	-5.16	-4.50	4.00	4.50	7.00
TV	*500+*	*500*	*400*	*300*	*200*	*100*	*50*	
M	9.00	8.00	7.50	7.25	7.00	6.75	2.50	
U	1.00	2.00	2.50	2.75	3.00	3.25	7.50	
M-U	8.00	6.00	5.00	4.50	4.00	3.50	-5.00	
U-M	-8.00	-6.00	-5.00	-4.50	-4.00	-3.50	5.00	
AG	*12*	*5.5*	*4*	*<4*				
M	9.25	7.65	5.00	2.30				
U	0.75	2.35	5.00	7.70				
M-U	8.50	5.30	0.00	-5.40				
U-M	-8.50	-5.30	0.00	5.40				
DNC	*1000+*	*750*	*500*	*250*	*200*			
M	9.00	7.25	5.00	2.75	1.00			
U	1.00	2.75	5.00	7.25	9.00			
M-U	8.00	4.50	0.00	-4.50	-8.00			
U-M	-8.00	-4.50	0.00	4.50	8.00			

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

Step 2: Determine factor weights

The importance is represented by the assigned weights for factors. This study chooses AHP pair wise comparison method to obtain weights w_i for each criterion C_i. The evaluation of each pair is based on the results from the nationwide survey.

Step 3: Determine preference function and preference degrees

In order to take the deviations and the scales of the criteria into account, a preference function is associated to each criterion. This study defines the preference function as $P(M,U)$ to represent the degree of the preference of alternative $Mark$ over $Unmark$ for criterion C_i. A revised linear threshold function is utilized similar to Type 5 in Table 1. The function is defined by Equations 5-7. Based on the criteria & scores from Tables 2, the preference function and degrees are established in Table 3.

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

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

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

Table 3 Preference Degree of Each Factor against Alternatives

PPT	*1*	*2*	*3*						
$P_1(M,U)$	1.00	0.00	0.00						
$P_1(U,M)$	0.00	0.00	1.00						
GL	*4L*	*3L*							
$P_2(M,U)$	0.00	0.61							
$P_2(U,M)$	0.00	0.00							
PRC	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*
$P_3(M,U)$	1.00	1.00	1.00	1.00	0.83	0.53	0.17	0.00	0.00
$P_3(U,M)$	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.50
MT	*N*	*Y*							

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

Step 4: Determine complete ranking scores of each alternative

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

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

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

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

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

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

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

The computational engine of the proposed guideline is implemented using Visual Basic for Application (VBA) programming in EXCEL. The weights are already input into the macro models. As discussed previously, if the difference between two preference scores is relatively small, the output will suggest Engineering Judgment (EJ) to assist the final decision. In conclusion, the developed guideline will present the likelihood of using a certain type of crosswalk at unsignalized locations.

4 CASE STUDY

The proposed guideline was applied in a case study. Two objectives of the case study are, (i) compare actual pedestrian crosswalk type with guideline proposal; (ii) test practicability and feasibility of the proposed guideline. Twenty-one unsignalized intersections in the City of Henderson and four in the City of Reno in Nevada State were selected as study sites. The case study was also implemented using VBA programming language in an EXCEL file which can be adapted to different agencies.

4.1 Comparison Result

Initially, twenty-five unsignalized intersections with 50% marked crosswalks and 50% unmarked crosswalks were analyzed. Model calibration was conducted at the first place. The policy preference tendency factor was input as 1-conservative, 2-moderate and 3-aggressive respectively. By comparing the existing condition with guideline recommendation, it indicated that Henderson has a higher percentage matching the aggressive judgment as shown in Figure 5. The matching result of Reno yet suggests that local agencies tend to hold a moderate attitude when it comes to crosswalk marking. At the same time, approximate 60% of all guideline proposals match actual field data. There are three reasons explaining the difference. Firstly, there was no consideration regarding pedestrian-related crash factor in either Reno or Henderson agencies when the crosswalk was installed. However, the pedestrian crash record is a quite important factor in the proposed guideline. Moreover, although both agencies currently took volume into account, it is more important to consider potential factors simultaneously and comprehensively as documented in the new guideline. Last but not least, the final preference scores are not divided into absolute two categories, mark and unmark, but the engineering judgment category is highly recommended when the difference between two final scores is less than 20%. This category is not included in real world data.

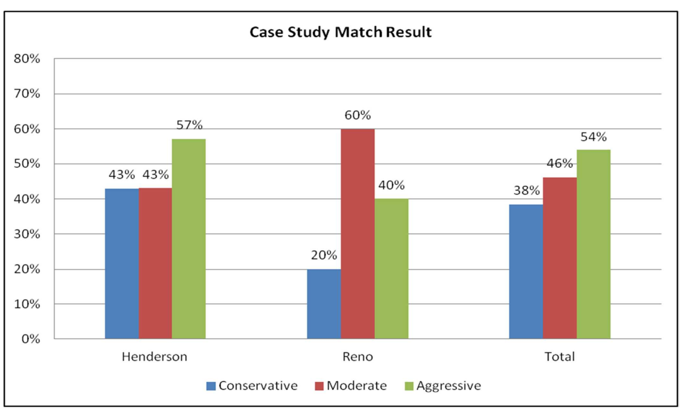


Figure 2 Case Study Match Results

4.2 Illustrative Example

An illustrative example is presented next to analyze N Virginia Street & 17th Street intersection in Reno, Nevada. This intersection is right next to UNR campus and the pedestrian crosswalk is unmarked at this location until this study conducted. The input data are shown in Table 4.

Table 4 Input Data

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

$$\pi(M,U)=\sum_{i=1}^{10} w_i P_i(M,U)=0.0559\times 0.0000+0.0304\times 0.6133+0.1829\times 0.1667+0.0263\times 0.0000 +0.0337\times 0.7533+0.2072\times 0.9933+0.1892\times 0.5000+0.0436\times 1.0000+0.1339\times 0.0000+0.0969\times 0.0000=0.4185$$

$$\pi(U,M)=\sum_{i=1}^{10} w_i P_i(U,M)=0.0559\times 0.0000+0.0304\times 0.0000+0.1829\times 0.0000+0.0263\times 0.5333 +0.0337\times 0.0000+0.2072\times 0.0000+0.1892\times 0.0000+0.0436\times 0.0000+0.1339\times 0.8000+0.0969\times 0.7500=0.1938$$

For this location, the global outranking of marking $\varphi(M)$ is greater than 0, the positive flows prevail while considering marking the crosswalk. The mark and unmark preference percentages are calculated for final decisions.

$$F(M)=\big(1+\varphi(M)\big)/2=(1+(\varphi^{+}(M)-\varphi^{-}(M)))/2=(1+(0.418492-0.193859))/2=0.6123=61\%;$$

$$F(U)=1-F(M)=0.3877=39\%$$

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

5 SUMMARY AND CONCLUSIONS

Pedestrian crosswalk marking is a useful traffic control device, but it is very important to realize the positive as well as the negative consequences of marking crosswalks. From the mobility point of view, marked crosswalks may seem to increase pedestrian mobility, but with perhaps a deceived sense of security. This study proposed a new guideline to direct the installation of crosswalk marking considering both mobility and safety contributing factors. The proposed guideline is following one of the basic multi-criteria methodologies named PROMETHEE method and incorporates key elements such as traffic and pedestrian volumes, geometry of the location, vehicle speed limit and pedestrian related crash record. The guideline was implemented using VBA programming in Excel which can be easily adapted by any agency and jurisdiction. The model calibration will by all means be needed to make sure it reflects specific location situations. In this study, case studies were conducted to verify the practicability and feasibility of the proposed guideline. The comparison results indicate that the new guideline can easily help engineers make sound decisions for the placement of marked crosswalks and interpret the dilemma of crosswalk markings.

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