Uncontrolled Pedestrian Crossing Evaluation Incorporating Highway Capacity Manual Unsignalized Pedestrian Crossing Analysis Methodology

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16. Abstract (Limit: 250 words)

This report provides a procedure for the evaluation of uncontrolled pedestrian crossing locations that takes into account accepted practice, safety and delay. Safety considerations have been paramount to the analysis of crossings but delay is often not considered. The Highway Capacity Manual (HCM) provides a methodology for determining delay that can be included in the analysis of a crossing location. The analysis procedure takes into account previous research procedures and adds in delay considerations to develop a methodology appropriate for use by jurisdictional agencies in the evaluation of what is needed for treatments at uncontrolled pedestrian crossings.

The evaluation procedure developed runs through a multi-step process from field data review through the consideration of appropriate treatment options. The evaluation procedure takes into account field data collection; safety/crash history; stopping sight distance; HCM Level of Service (LOS); pedestrian sight distance; origins and destinations/alternate routes; access spacing and functional classification; roadway speed and pedestrian use; FHWA guidance for placement based on safety considerations; school crossings; and appropriate treatment options. Treatment options include four different classes: Signing and Marking Treatments; Traffic Calming Treatments; Uncontrolled Crossing Treatments; and High Level Treatments.

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Executive Summary

Pedestrian crossings are an important aspect of the multi-modal transportation system. While they are essential to get pedestrians across highways and streets, they are a concern for jurisdictional authorities of highways and streets due to the numerous locations and concerns for pedestrian safety. In support of this, state statutes generally support the rights of pedestrians at crossing locations. According to Minnesota State Statutes, the driver of a vehicle shall stop for a pedestrian at all marked crosswalks and at all intersections. While motorists are required to stop for pedestrians in these situations, some pedestrians may indicate that additional measures are needed to be able to safely cross at a specific crossing location, especially as many motorists do not follow the law and stop when required. Additionally, in any crash between a vehicle and pedestrian, the chance of the pedestrian being severely injured or killed is high, leading pedestrians to not take chances and wait for an adequate gap in traffic before even attempting to start to cross.

Traffic signals can provide an adequate gap by controlling when traffic, vehicles and pedestrians alike, are to move or stop, but the traffic volume necessary to justify a signal can be quite high. Of more significance to understand is how to provide adequate gaps and increased safety at uncontrolled pedestrian crossing locations.

When traffic volume is high enough, adequate gaps can be difficult to attain. While marking a crosswalk can provide an indication to vehicle traffic that there is a potential for crossing pedestrians, a crosswalk does not make a motorist stop. Consequentially, marked crosswalks do not necessarily provide any increase in safety for a pedestrian. There is significant research into the safety considerations of uncontrolled pedestrian crossings when they are marked versus unmarked. This research generally indicates that pedestrian crash rates increase when these crossings are marked versus unmarked under most situations. This has been applied by many jurisdictional agencies for the evaluation of pedestrian crossings on their roadways. In support of this, the Manual on Uniform Traffic Control Devices (MUTCD) states that an engineering study should be completed before a marked crosswalk is installed at any location an approach is not controlled by a signal, yield or stop sign. While an engineering study that takes into account only safety research may be appropriate for many crossings, it may also be appropriate to consider operations in addition to safety, as is applied to vehicle traffic analysis.

The Highway Capacity Manual (HCM) provides a procedure for evaluating operations through pedestrian crossing delay. The research used to develop the methodology indicates that as delay increases at a crossing location due to motorists not stopping for the pedestrians, pedestrians take more risks to complete a crossing maneuver, similar to the way vehicles that experience high delay will also complete high-risk maneuvers. This impact should not be ignored. As of this research study, the HCM procedure has not been widely applied to the evaluation of pedestrian crossings but can help to provide an equivalent process to vehicle intersection operational analysis and be applied to the MUTCD engineering study requirement.

This research provides a procedure for the evaluation of uncontrolled pedestrian crossing locations that takes into account both safety and delay. The analysis procedure takes into account previous research to develop a methodology that is appropriate for jurisdictional agencies. As

this research was completed in Minnesota, the policies and standards mentioned in the study are from Minnesota where possible.

The evaluation procedure runs through a multi-step process from field data review through the consideration of appropriate treatment options. The specific steps include

- Field Data Review
- Safety Review
- Stopping Sight Distance Analysis
- HCM Level of Service (LOS) Analysis
- Pedestrian Sight Distance Analysis
- Review of Origins and Destinations and Alternate Routes
- Review of Access Spacing and Functional Classification
- Review of Speed and Pedestrian Use
- Review of FHWA Safety Guidance
- School Crossing Considerations
- Consideration of Appropriate Treatment Options
    - Signing and Marking Treatments
    - Traffic Calming Treatments
    - Uncontrolled Crossing Treatments
    - High-Level Treatments

The background, understanding and analysis methodology of each step in the process is introduced. A summary of appropriate crossing treatments, their advantages and disadvantages, recommended locations, estimated costs, and their impact on pedestrian yield rates as it relates to the HCM analysis are provided. In support of the analysis procedure, real world examples from Minnesota are shown to guide users through the evaluation and analysis process.

Chapter 1
Introduction

Pedestrian crossings are an important feature of the multi-modal transportation system. They enable pedestrians and bicyclists to cross conflicting traffic to access locations on either side of streets and highways. Pedestrian crossings can either be marked or unmarked.

According to 2013 Minnesota State Statutes, the driver of a vehicle shall stop to yield the right-of-way to a pedestrian at all intersections and at all marked crosswalks at unsignalized locations. Additionally, a pedestrian crossing a roadway at any location other than within a marked crosswalk or at an intersection shall yield the right-of-way to all vehicles upon the roadway. [1]

While the state statute says that a motorist shall stop for a pedestrian that is within a marked crosswalk or crossing at an intersection, the opportunities in which a motorist actually stops for a pedestrian and yields the right-of-way may be few. Additionally, when the traffic volumes are high enough that there are few gaps in traffic adequate for a pedestrian to cross a roadway safely, pedestrians may have a difficult time crossing. Consequently, either case can result in pedestrian crossings that are challenging and result in high delay for the pedestrian, which can lead to pedestrians taking higher risks.

Providing safe crossing situations for pedestrians relies on not only placing crosswalks at "safe" locations but also providing facilities where pedestrians are crossing with minimal delay. Placing crosswalk markings, signs, or other treatments at pedestrian crossing locations without understanding the needs of pedestrians in the area may result in the overuse of crossing markings and treatments that are not necessary and actually result in a less safe crossing environment. In support of the need to evaluate crossing locations, the Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) states that crosswalk pavement markings should not be placed indiscriminately and an engineering study should be completed when crosswalk markings are being contemplated at a crossing. [2]

Defining where to place pedestrian crossing facilities including markings and signs depends on many factors including pedestrian volume, vehicular traffic volume, sight lines, and speed. Additionally, there are locations in which pedestrians would like to cross the street, but the traffic volume is so high that there are not adequate gaps in the traffic stream to safely cross. This results in a high delay crossing which then results in a high risk-taking environment, decreasing safety.

The methodology for the evaluation of pedestrian crossings presented here attempts to evaluate the adequacy of uncontrolled pedestrian crossing locations based on both safety and operations. A companion to this evaluation methodology is Minnesota's Best Practices for Pedestrian / Bicycle Safety which provides information on available pedestrian safety strategies.

This manual presents an engineering methodology that takes into account both safety and operations for the evaluation of uncontrolled pedestrian crossings. This includes crossings at both mid-block and intersections in which the cross-street traffic is not controlled by a stop sign, yield sign, or signal.

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Chapter 2
Background

The Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) states that crosswalk markings should not be used indiscriminately and that an engineering study should be completed when using crosswalk markings.

Objective and Scope:
The objective of this methodology is to provide a study procedure for the evaluation of uncontrolled pedestrian crossing locations that takes into account accepted practice, safety, and operations.

State of the Practice:
Crossing evaluation methods, best practices, and sources for development of the evaluation procedure will be presented.

Data Collection and Field Review:
A methodology for the field review and data collection will be presented. A Data Collection Worksheet has been developed that can be used to complete the field data collection.

Safety:
The Federal Highway Administration provides extensive research into the safety of pedestrian crossings based on the number of lanes being crossed, vehicle volume, and travel speed. The safety evaluation table will be presented.

Operations:
The Highway Capacity Manual provides a comprehensive evaluation methodology for determining the operations of a crossing location through the calculation of average delay for a pedestrian at a crossing location. The HCM procedure will be presented.

The 2010 HCM updates the previous evaluation procedure in the 2000 HCM to account for the effect of yielding of vehicles to pedestrians based on different crossing treatments beyond pavement markings and signs only.

Evaluation Procedure:
An uncontrolled pedestrian crossing location evaluation procedure and flowchart will be presented.

Examples:
Real world examples of different types of pedestrian crossing locations will be presented. This includes a field review and crossing evaluation.

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Chapter 3
State of the Practice

The information presented here is a summary of the information in each referenced document as it relates to pedestrian crossing evaluations. Please refer to the actual document for the full text and explanations.

Minnesota State Statutes [1]

Minnesota State Statutes regarding the rights of pedestrians at unsignalized pedestrian crossings are defined in section 169.21, subdivision 2a, 3a, 3b, 3c, and 3d.
It is not the intention of this summary to be all inclusive to all laws regarding pedestrian crossings. No lawyers or legal representatives have reviewed the material and as such should not be taken to be all-inclusive. Consultation with legal representatives and review of the full state statutes is advised in reference to any and all legal matters.

> "169.21 PEDESTRIAN.
> Subd. 2.Rights in absence of signal.
> (a) Where traffic-control signals are not in place or in operation, the driver of a vehicle shall stop to yield the right-of-way to a pedestrian crossing the roadway within a marked crosswalk or at an intersection with no marked crosswalk. The driver must remain stopped until the pedestrian has passed the lane in which the vehicle is stopped. No pedestrian shall suddenly leave a curb or other place of safety and walk or run into the path of a vehicle which is so close that it is impossible for the driver to yield. This provision shall not apply under the conditions as otherwise provided in this subdivision.
> Subd. 3. Crossing between intersections.
> (a) Every pedestrian crossing a roadway at any point other than within a marked crosswalk or at an intersection with no marked crosswalk shall yield the right-of-way to all vehicles upon the roadway.
> (b) Any pedestrian crossing a roadway at a point where a pedestrian tunnel or overhead pedestrian crossing has been provided shall yield the right-of-way to all vehicles upon the roadway.
> (c) Between adjacent intersections at which traffic-control signals are in operation pedestrians shall not cross at any place except in a marked crosswalk.
> (d) Notwithstanding the other provisions of this section every driver of a vehicle shall (1) exercise due care to avoid colliding with any bicycle or pedestrian upon any roadway and (2) give an audible signal when necessary and exercise proper precaution upon observing any child or any obviously confused or incapacitated person upon a roadway." [1]

Important Points:

1. All intersections include legal pedestrian crossings whether marked or unmarked.
2. When a crossing is not signalized, the driver of a vehicle shall stop to yield the right-of-way to pedestrians within marked crosswalks and at all intersections with marked or unmarked crosswalks.
3. Pedestrians shall yield right-of-way to all vehicles upon the roadway at any point other than at intersections or marked crosswalks.

Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD); January 2014 [2]

The MN MUTCD contains standards for traffic control devices that regulate, warn, and guide users along all roadways within the State of Minnesota. The MN MUTCD standards are to be followed on all roadways, public or private within the state.

Crosswalk Markings

Support, Guidance, and Standards for crosswalk markings are included in Section 3B.18 of the MN MUTCD.

> "Support:
> Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops.
>
> In conjunction with signs and other measures, crosswalk markings help to alert road users of a designated pedestrian crossing point across roadways at locations that are not controlled by traffic control signals or STOP or YIELD signs.
>
> At non-intersection locations, crosswalk markings legally establish the crosswalk.
>
> Standard:
> When crosswalk lines are used, they shall consist of solid white lines that mark the crosswalk. They shall not be less than 6 inches or greater than 24 inches in width.
>
> Guidance:
> Crosswalk lines should not be used indiscriminately. An engineering study should be performed before a marked crosswalk is installed at a location away from a traffic control signal or an approach controlled by a STOP or YIELD sign. The engineering study should consider the number of lanes, the presence of a median, the distance from adjacent signalized intersections, the pedestrian volumes and delays, the average daily traffic (ADT), the posted or statutory speed limit or 85th-percentile speed, the geometry of the location, the possible consolidation of multiple crossing points, the availability of street lighting, and other appropriate factors.
> New marked crosswalks alone, without other measures designed to reduce traffic speeds, shorten crossing distances, enhance driver awareness of the crossing, and/or provide active warning of pedestrian presence, should not be installed across uncontrolled roadways where the speed limit exceeds 40 mph and either:
> A. The roadway has four or more lanes of travel without a raised median or pedestrian refuge island and an ADT of 12,000 vehicles per day or greater; or
> B. The roadway has four or more lanes of travel with a raised median or pedestrian refuge island and an ADT of 15,000 vehicles per day or greater.

Guidance:
Because non-intersection pedestrian crossings are generally unexpected by the road user, warning signs should be installed for all marked crosswalks at non-intersection locations and adequate visibility should be provided by parking prohibitions.” [2]

Important Points

1. Crosswalk markings legally establish the location of a crosswalk at non-intersection locations.
2. When used, crosswalks shall consist of solid white lines that mark the crosswalk.
3. New marked crosswalks, in the absence of other measures, should not be installed across uncontrolled roadways where the speed limit exceeds 40 mph and either:
    a. Roadway > 4 travel lanes
       Without a raised median
       ADT > 12,000
    b. Roadway > 4 travel lanes
       With a raised median
       ADT > 15,000
4. An Engineering study should be completed before a marked crosswalk is installed at any location that an approach is not controlled by a signal, yield, or stop sign.

<u>Signs</u>

Support, Guidance, and Standards for signs associated with pedestrian crossing are included in multiple sections of the MN MUTCD. The sections that pertain to the signs presented in this manual include

- 2B.11: Stop Here For Pedestrian Signs,
- 2B.12: In-Street and Overhead Pedestrian Crossing Signs,
- 2C.49: Vehicular Traffic Signs,
- 2C.50: Non-Vehicular Signs,
- 7B.8: School Signs and Plaques,
- 7B.11: School Advance Crossing Assembly, and
- 9B.18: Bicycle Warning and Combined Bicycle/Pedestrian Signs.

<u>Warning Signs</u>

Pedestrian warning signs (W11-2) are considered non-vehicular warning signs. Other warning signs may be used at crossings depending on the facility using the crossing, be it pedestrians only (W11-2), bicyclists (W11-1), or a combination (W11-15). Under most circumstances the W11-1 should be used for bike trail crossings, W11-2 should be used for pedestrian crossings, while W11-15 should be used for multi-use trail crossings. Additionally, school crossings have the S1-1 sign. This manual focuses on pedestrian warning signs, but practitioners should be aware that there are different warning signs available for crossings and the support, guidance, and standards for each depend on the type of crossing facility. [2]

W11-1

W11-2

W11-15

S1-1

Pedestrian warning signs may be used to alert road users in advance of a pedestrian crossing location where unexpected entries into the roadway might occur or where shared use of the roadway by pedestrians might occur. They may be placed in advance of a crossing location and/or at the crossing location.

> "Non-vehicular signs should be used only at locations where the crossing activity is unexpected or at locations not readily apparent."

> "The crossing location identified by a W11-2 sign may be defined with crosswalk markings."

The S1-1 sign can be used is the same way as a pedestrian warning sign except that it is used to indicate where schoolchildren are crossing the roadway. [2]

Supplemental Plaques

> "If used in advance of a pedestrian crossing, the W11-2 signs should be supplemented with plaques with the legend AHEAD or XX FEET to inform road users that they are approaching a point where crossing activity might occur."

W16-9P

W16-2P

While the above plaques are included in the MN MUTCD many jurisdictions do not install them, especially if the crossing location is visible from the advance warning sign location. The plaques do provide additional information to the motorist about where the crossing is located if the crossing cannot be readily seen.

> "If a post-mounted W11-2 sign is placed at the location of the crossing point where pedestrians might be crossing the roadway, a diagonal downward pointing arrow (W16-7P) plaque shall be mounted below the sign. If the W11-2 sign is mounted overhead, the W16-7P plaque shall not be used." [2]

In Minnesota, the W16-7P has been modified with a larger sign consistent in size with other arrow signs (16-7mP).

W16-7mP

"A Pedestrian Crossing (W11-2) sign may be placed overhead or may be post-mounted with a diagonal downward pointing arrow (W16-7P) plaque at the crosswalk location where Yield Here To (Stop Here For) Pedestrians signs have been installed in advance of the crosswalk." [2]

Stop Here For Pedestrians Signs

"If a W11-2 sign has been post-mounted at the crosswalk location where a Stop Here For Pedestrians sign is used on the approach, Stop Here For Pedestrians sign shall not be placed on the same post as or block the road user's view of the W11-2 sign."

"Stop Here For Pedestrians (R1-5b or R1-5c) signs shall be used if stop lines are used in advance of a marked crosswalk that crosses an uncontrolled multi-lane approach. The Stop Here for Pedestrians signs shall only be used where the law specifically requires that a driver must stop for a pedestrian in a crosswalk." [2]

R1-5b

R1-5c

"If stop lines and Stop Here For Pedestrians signs are used in advance of a crosswalk that crosses an uncontrolled multilane approach, they should be placed 20 to 50 feet in advance of the nearest crosswalk line (see Section 3B.16 and Figure 3B-17), and parking should be prohibited in the area between the stop line and the crosswalk." [2]

Figure 3.1 Example of Advance Stop Bar
Bloomington [3]

Figure 3.2 Example of Advance Stop Bar
Burnsville

"An advance Pedestrian Crossing (W11-2) sign with an AHEAD or a distance supplemental plaque may be used in conjunction with a Stop Here For Pedestrians sign on the approach to the same crosswalk." [2]

"When drivers yield or stop too close to crosswalks that cross uncontrolled multi-lane approaches, they place pedestrians at risk by blocking other drivers' views of pedestrians and by blocking pedestrians' views of vehicles approaching in the other lanes." [2]

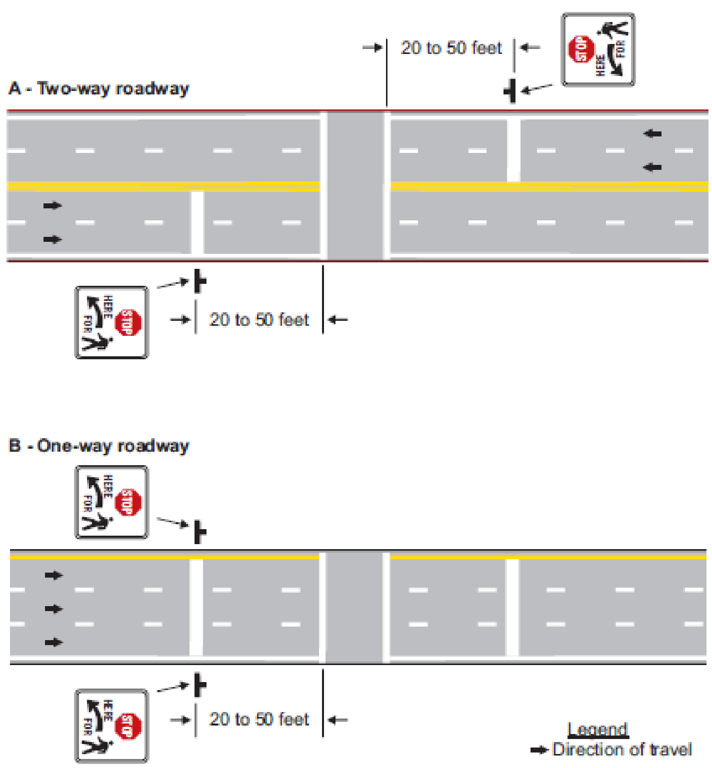


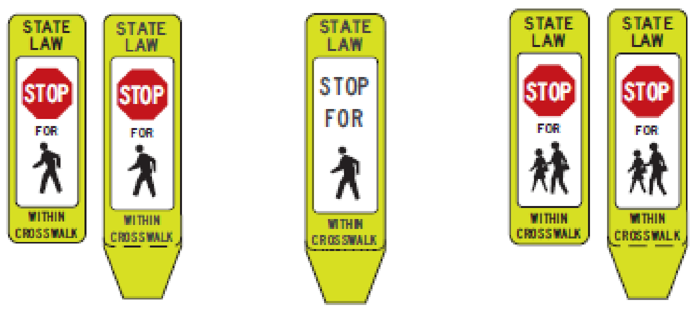
Figure 3.3 Example of Stop Lines at Unsignalized Midblock Crosswalks [2]

The advance stop bars with the pedestrian signs have been shown to improve motorist yielding on multi-lane facilities. [4]

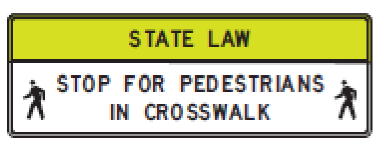
<u>In-Street and Overhead Pedestrian Crossing Signs</u>

> "In-Street Pedestrian Crossing signs and Stop Here For Pedestrians signs may be used together at the same crosswalk."

> "The In-Street Pedestrian Crossing (R1-6a or R1-6b) sign or the Overhead Pedestrian Crossing (R1-9b) sign may be used to remind road users of laws regarding right-of-way at an unsignalized pedestrian crosswalk. The legend STATE LAW may be displayed at the top of the R1-6a, R1-6b, and R1-9b signs, if applicable." [2]



R1-6a **R1-6b** **R1-6c**



R1-9b

The R1-6c is also provided for use at school crossing locations. The R1-6a is recommended over the R1-6b sign as visual symbols are more easily understood by all motorists.

> "In order to avoid overuse, the In-Street Pedestrian Crossing sign should only be used at locations having high pedestrian crossings." [2]

<u>Warning Sign Color</u>

All of the warning signs and supplemental plaques may have a fluorescent yellow-green background with a black legend and border.

> "When a fluorescent yellow-green background is used, a systematic approach featuring one background color within a zone or area should be used. The mixing of standard

yellow and fluorescent yellow-green backgrounds within a selected site area should be avoided.” [2]

Warning Beacons

“A Warning Beacon may be used with any Non-Vehicular Warning sign to indicate specific periods when the condition or activity is present or is likely to be present, or to provide enhanced sign conspicuity.

A supplemental WHEN FLASHING (W16-13P) plaque may be used with any Non-Vehicular Warning sign that is supplemented with a Warning Beacon to indicate specific periods when the condition or activity is present or is likely to be present.” [2]

W16-13P

Important Points

1. Pedestrian crossing signs may be used to alert road users to locations where unexpected entries onto the roadway by pedestrians may occur.
2. Pedestrian crossing signs may be placed in advance of and at the pedestrian crossing location.
3. If pedestrian crossing signs are installed at the crossing location, they shall include a diagonal downward pointing arrow.
4. Pedestrian crossing signs may or may not be installed with crosswalk markings.
5. On multi-lane approaches, if an advance stop bar is used, Stop Here For Pedestrians signs shall also be used.
6. In-Street Pedestrian crossing signs may be used to supplement pedestrian warning signs at high pedestrian volume locations.

Raised Medians

Support for raised medians is included in Section 3I.6 of the MN MUTCD.

“Raised islands or medians of sufficient width that are placed in the center area of a street or highway can serve as a place of refuge for pedestrians who are attempting to cross at a midblock or intersection location. Center islands or medians allow pedestrians to find an adequate gap in one direction of traffic at a time, as the pedestrians are able to stop, if necessary, in the center island or median area and wait for an adequate gap in the other direction of traffic before crossing the second half of the street or highway. The minimum widths for accessible refuge islands and for design and placement of detectable warning surfaces are provided in the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)".” [2]

Traffic Engineering Manual, State of Minnesota Department of Transportation [5]

MnDOT has set up a procedure to evaluate whether a crossing location is appropriate for treatments such as marked crosswalks or pedestrian crossing warning signs. The guidance uses elements which to make a decision whether to install a crossing or if crossing treatments are appropriate at a particular location. The Traffic Engineering Manual states that an engineering study should be completed to determine the necessity of a pedestrian crosswalk. The engineering study should consider

- Geometrics,
- Motorist sight distance,
- Traffic volume data including truck traffic and turning movements,
- Daily pedestrian volume estimates,
- Observation of site characteristics that could divert driver attention from the crosswalk,
- Posted speed limit,
- Crash history, and
- Sidewalks and pedestrian pathways. [5]

This analysis performed on potential crosswalk location should result in a more uniform application and it is noted that not all sites warrant a pedestrian crossing or a crosswalk with additional treatments. The non-uniform application, misuse, or overuse of crosswalk safety treatments may result in:

- Noncompliance with traffic control devices,
- Decrease in safety, and/or
- Disregard of traffic control device.

The guidance also lays out a decision flowchart to help decision makers determine whether or not a crosswalk is warranted. The flowchart sets out certain conditions that must be met at all crosswalk locations. This includes

- Adequate stopping sight distance for motorists,
- Minimal truck traffic,
- Minimal vehicle turning movements, and
- Minimal driver distractions. [5]

While Stopping Sight Distance can be easily calculated and evaluated, the flowchart and documents do not quantify any of the other elements above, and so is left open to interpretation. The flowchart sets up a decision tree that has three potential outcomes:

1. Condition Red (Relatively High Risk)
    a. Crosswalk not recommended.
    b. If pedestrian warrants are met, other treatments could be added such as: pedestrian bridge, pedestrian underpass, or pedestrian signal.
2. Condition Yellow (Relatively Medium Risk)
    a. Eligible for crosswalk with additional treatments.
    b. Design options that may be considered include
        i. Modify existing lane configurations,
        ii. Raised median (minimum width of four feet and length of eight feet),
        iii. Curb extensions,

iv. Pedestrian Crossing Island,
v. Advanced stop lines and associated signing,
vi. Parking restrictions,
vii. Increased law enforcement, and/or
viii. Modify and/or add lighting.

c. Some Condition Yellow crossings may be determined sufficient without crosswalk enhancements.

3. Condition Green (Relatively Low Risk)
   a. Eligible for crosswalk with no or minimal additional treatments.
   b. Typically only require pavement markings.
   c. Should be selected to address a specific problem.
   d. Evaluate need for advance signing and pavement messages. [5]

Based on this criteria, a condition red would disqualify a crossing location from being signed and striped. The most common reason for this is: having less than 20 pedestrians per hour and no elderly or child facilities nearby; speed limit is greater than 40 mph; ADT is greater than 12,000; and/or there are more than 4 lanes.

Guidelines for placement of school crossings are also mentioned. This includes placement of School Advance Warning assemblies, crosswalks within a school zone, and roadway messages.

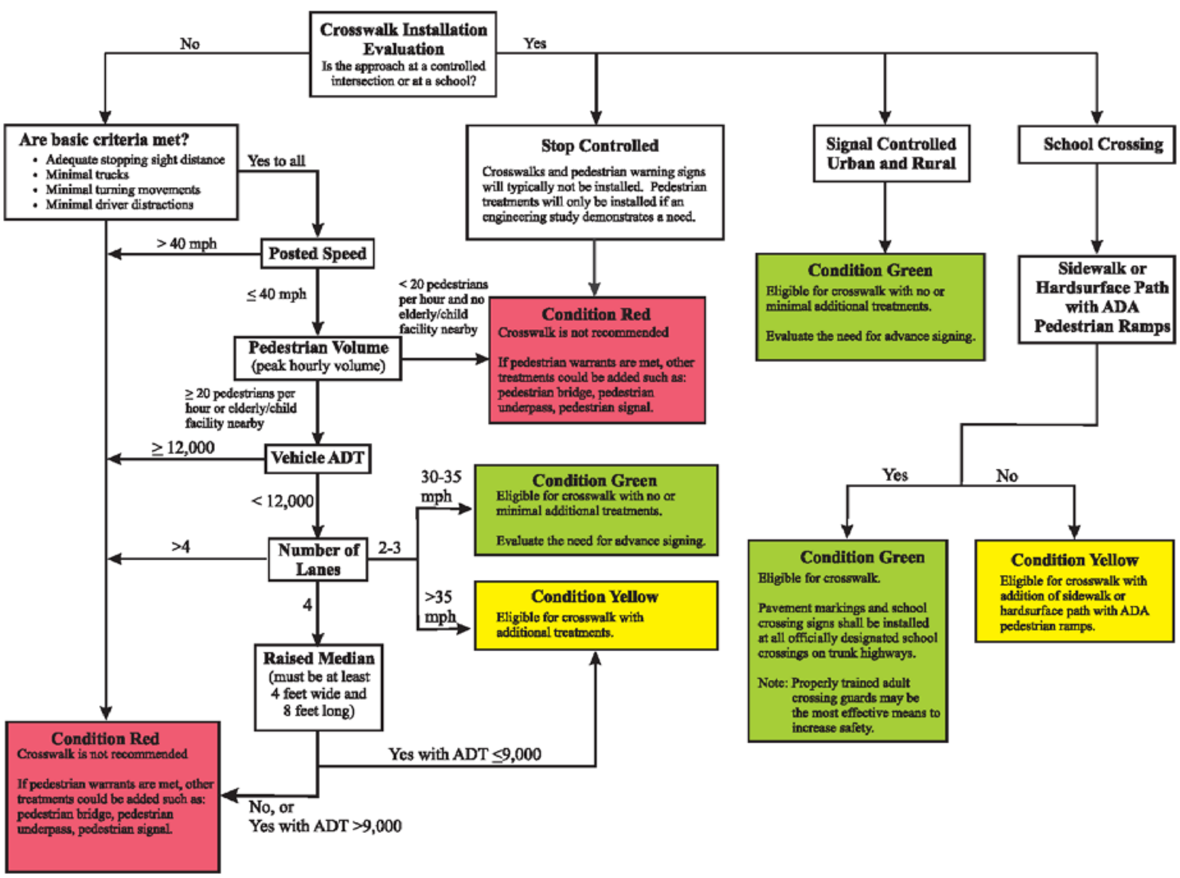


Figure 3.4 MnDOT Crosswalk Installation Flowchart

A Policy on Geometric Design of Highways and Streets (Green Book) [6]

The AASHTO Green Book includes some general considerations for pedestrians but is primarily focused on vehicles. Of interest is a list of suggested measures with the potential to aid older pedestrians.

- Use simple designs that minimize crossing widths and minimize the use of complex elements. Consider 11 foot lane widths.
- Assume lower walking speeds
- Provide median refuge islands
- Provide lighting and eliminate glare sources
- Provide adequate guide signs
- Use enhanced traffic control devices
- Provide enhanced markings and delineation
- Use repetition and redundancy in design and signing [6]

Pedestrians have a wide range of walking speeds at which they will cross a street. Typical pedestrian walking speeds range from approximately 2.5 to 6.0 ft/s. Advanced age is the most common cause for slower walking speeds, and in areas with older people, a speed of 2.8 ft/s should be considered for use in design. [6]

Another item especially important in the planning of pedestrian crossings, is Stopping Sight Distance (SSD). In assessing and determining the location of a pedestrian crossing it is important that a vehicle be able to see a pedestrian crossing at the location and be able to stop in adequate time.

Stopping Sight Distance is the length of roadway ahead that is needed for stopping and includes both brake reaction time and braking distance. [6]

$$SSD = 1.47Vt + 1.075\frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \pm G\right]}$$

where:

SSD = Stopping Sight Distance
V = design speed (mph)
t = brake reaction distance, 2.5 s
a = deceleration rate, ft/s^2
G = grade, rise/run, ft/ft

The second part of the equation is the braking distance. It may be important to consider the vertical grades in some areas which can increase or decrease the braking distance.

Guide for the Planning, Design, and Operation of Pedestrian Facilities [7]

"The purpose of the guide is to provide guidance on the planning, design, and operation of pedestrian facilities along streets and highways." [7] While this is an extensive document, specific sections are of direct interest to this study.

Walk decisions are primarily based upon three factors: travel distance; personal safety and security; and personal comfort and attractiveness. [7]

Pedestrian walking speeds range from 2.5 to 6.0 ft. per sec. The busier a crossing is, the slower the speed of pedestrians. Wheelchair and scooter users require wider paths and ramps for travel. Cross grades should not be steeper than 2%. [7]

Transit networks rely on pedestrian access. [7]

During project planning crossing measures are needed to ensure frequent and safe opportunities to cross a corridor. "Crossing distances should be kept to a minimum. New construction or altered walkways and street crossing shall be accessible to the maximum extent possible." Extra care is necessary when developing street crossing near schools. Children are smaller and motorists may have difficulty seeing them. Ensure objects do not inhibit the ability to see children. [7]

The design details on crossings should be followed and evaluated when completing a field review of crossings.

- Crosswalks, landing areas, corners and other parts of the pedestrian route should be clear of obstructions.
- Pedestrians should have a clear view of travel lanes and motorists.
- Symbols, signs, and markings should clearly indicate what actions a pedestrian should take.
- Curb ramps are required to have adequate maneuvering space and detectable warnings. Detectable truncated dome warnings must be provided for the full width of ramps to mark the street edge. Curb ramps to be a minimum of four feet wide but should match the width of the pedestrian route.
- Adequate lighting should be included if pedestrians are present during nighttime hours. In areas of heavy growth, lighting may need to be evaluated when there is full growth. Midblock crossings have additional considerations when compared to corner crossings. Midblock crossings are located according to a number of factors including pedestrian volume, desired paths for pedestrians, roadway width, or the volume of pedestrians or vehicles. They should not be installed where sight distance or sight lines are limited for either the motorist or pedestrian. The design details on crossings should be followed and evaluated when completing a field review of mid-block crossings. [7]

The guidance provide attributes where midblock crossings can be most effective. Some of the attributes include:

- Location is already a source for substantial midblock crossings
- Land use is such that pedestrians are unlikely to cross at the next intersection

- Safety and capacity of adjacent intersections or large turning volumes creates a difficult crossing situation
- Spacing between adjacent intersections exceeds 660 ft. [7]

Medians or crossings islands are recommended at mid-block crossing locations. Midblock pedestrian crossings should be supplemented with warning signs. Overhead warning signs can improve motorist awareness of the crossing. Parking should be reviewed for impacts to sight distance. [7]

If grade-separated crossings are an alternative at a crossing location, the use of the grade separated crossing depends on the time to use each alternative route. If the crossing time of the “safe” route (underpass or overpass) is generally more than the crossing time at ground level, there is a high probability that pedestrians will not use the “safe” route. [7] The document uses the word “safe” to describe an underpass or overpass but at-grade options can also be designed “safe.”

Table 3.1 Percent of Pedestrians Using the a Bridge or Tunnel Route

Travel Times	Bridge	Tunnel
Equal	15 to 60%	95%
30% Longer on Safe Route	0%	25 to 70%
50% Longer on Safe Route	0%	0%

This may also be of consideration when evaluating the effectiveness of an alternative route versus just waiting at the existing at-grade crossing.

Minnesota’s Best Practices for Pedestrian/Bicycle Safety [8]

The Best Practices Guide is a resource to assist agencies in the effort to safely accommodate pedestrians and bicyclists on roads and highways. The information is primarily presents the guidance prepared by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP). The strategies focus on the best practices to reduce the number of severe crashes involving pedestrians and bicyclists. The guide provides information on different strategies to reduce the number of pedestrian and bicyclist crashes based on a proven, tried, or experimental basis. The guide explanations of each type of strategy, the crash reduction, operational effects, candidate locations, design features and estimated construction costs. Specific strategies mentioned in the guide as it is related to uncontrolled pedestrian crossings include:

- Crosswalks and Crosswalk Enhancements,
- Medians and Crossing Islands,
- Curb Extensions,
- Pedestrian Hybrid Beacon System,
- Rectangular Rapid Flashing Beacon,

- Crosswalk Lighting,
- Traffic Signals,
- Grade Separated Crossing, and
- Crossing Guards.

This guide should be used a go to source to understand specific safety strategies in more detail. Some of this information is included in Chapter 8.

Best Practices Synthesis and Guidance in At-Grade Trail Crossing Treatments [9]

The document presents best practices observed in Minnesota, as well as nationally, for guidance on safety treatment applications at trail crossings. The guide provides a standardized procedure to determine options based on the needs of the individual trail crossings. An extensive decision tree is provided to determine possible options for individual crossings. The roadway crossing features needed for the decision tree include urban/rural, two-lane/multi-lane, undivided/divided, speed limit, traffic volume, and crossing location. The treatments presented are not intended for crossings other than trail crossings and do not include intersection crossings. Many of the treatment options are also presented in detail to understand what the treatment options contain. Some of this information is included in Chapter 8.

Improving Pedestrian Safety at Unsignalized Crossings [10]

The study developed guidelines that can be used to select pedestrian crossing treatments for unsignalized intersections and midblock locations. The procedures in the guidelines use variables such as pedestrian volume, street crossing width, and traffic volume to recommend one of four possible crossing treatment categories. The research provided recommendations to revise the MUTCD pedestrian warrant for traffic control signals to the National Committee on Uniform Traffic Control Devices.

The research also provided information on walking speed and motorist compliance. Pedestrian walking speed recommendations were 3.5 ft/s for the general population and 3.0 ft/s for the older or less able population. Motorist compliance was the primary measure of effectiveness for engineering treatments at unsignalized roadway crossings. The study found that the type of crossing treatment affects motorist compliance; other factors influencing the treatment effectiveness were the number of lanes being crossed and posted speed limit.

The document does present a flowchart for guidelines for pedestrian crossing treatments. It also provides worksheets which are a precursor to the methodology presented in the Highway Capacity Manual for evaluation based on pedestrian delay.

WORKSHEET 1: PEAK-HOUR, 35 MPH (55 KM/H) OR LESS

Analyst and Site Information	
Analyst: Analysis Date: Data Collection Date:	Major Street: Minor Street or Location: Peak Hour:

Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street): a) Worksheet 1 – 35 mph (55 km/h) or less b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists		
Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?		
Peak-hour pedestrian volume (ped/h), V_p	*2a*	
If *2a* ≥ 20 ped/h, then go to Step 3.		
If *2a* < 20 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.		
Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?		
Major road volume, total of both approaches during peak hour (veh/h), $V_{maj\text{-}s}$	*3a*	
Minimum signal warrant volume for peak hour (use *3a* for $V_{maj\text{-}s}$), SC $SC = (0.00021\ V_{maj\text{-}s}^2 - 0.74072\ V_{maj\text{-}s} + 734.125)/0.75$ OR $[(0.00021\ 3a^2 - 0.74072\ 3a + 734.125)/0.75]$	*3b*	
If *3b* < 133, then enter 133. If *3b* ≥ 133, then enter *3b*.	*3c*	
If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce *3c* by up to 50 percent; otherwise enter *3c*.	*3d*	
If *2a* ≥ *3d*, then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.		
Step 4: Estimate pedestrian delay.		
Pedestrian crossing distance, curb to curb (ft), L	*4a*	
Pedestrian walking speed (ft/s), S_p	*4b*	
Pedestrian start-up time and end clearance time (s), t_s	*4c*	
Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c)]$	*4d*	
Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), $V_{maj\text{-}d}$	*4e*	
Major road flow rate (veh/s), $v = V_{maj\text{-}d}/3600$ OR $[4e/3600]$	*4f*	
Average pedestrian delay (s/person), $d_p = (e^{v\,t_c} - v\,t_c - 1)/v$ OR $[(e^{4f \times 4d} - 4f \times 4d - 1)/4f]$	*4g*	
Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$ (this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.	*4h*	
Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.		
Expected motorist compliance at pedestrian crossings in region, Comp = high or low	*5a*	

Total Pedestrian Delay, D_p (from *4h*) and Motorist Compliance, Comp (from *5a*)	**Treatment Category** (see Descriptions of Sample Treatments for examples)
$D_p \geq 21.3$ h (Comp = high or low) OR $5.3 \text{ h} \leq D_p < 21.3$ h and Comp = low	RED
$1.3 \text{ h} \leq D_p < 5.3$ h (Comp = high or low) OR $5.3 \text{ h} \leq D_p < 21.3$ h and Comp = high	ACTIVE OR ENHANCED
$D_p < 1.3$ h (Comp = high or low)	CROSSWALK

Figure 3.5 Pedestrian Safety Crossing Treatments Worksheet 1: 35 MPH or Less

WORKSHEET 2: PEAK-HOUR, EXCEEDS 35 MPH (55 KM/H)

Analyst and Site Information	
Analyst: Analysis Date: Data Collection Date:	Major Street: Minor Street or Location: Peak Hour:

Step 1: Select worksheet (speed reflects posted or statutory speed limit or 85th percentile speed on the major street):
a) Worksheet 1 – 35 mph (55 km/h) or less
b) Worksheet 2 – exceeds 35 mph (55 km/h), communities with less than 10,000, or where major transit stop exists

Step 2: Does the crossing meet minimum pedestrian volumes to be considered for a TCD type of treatment?		
Peak-hour pedestrian volume (ped/h), V_p	*2a*	
If *2a* ≥ 14 ped/h, then go to Step 3.		
If *2a* < 14 ped/h, then consider median refuge islands, curb extensions, traffic calming, etc. as feasible.		

Step 3: Does the crossing meet the pedestrian volume warrant for a traffic signal?		
Major road volume, total of both approaches during peak hour (veh/h), V_{maj-s}	*3a*	
Minimum signal warrant volume for peak hour (use *3a* for V_{maj-s}), SC $SC = (0.00035\ V_{maj-s}^2 - 0.80083\ V_{maj-s} + 529.197)/0.75$ OR $[(0.00035\ 3a^2 - 0.80083\ 3a + 529.197)/0.75]$	*3b*	
If *3b* < 93, then enter 93. If *3b* ≥ 93, then enter *3b*.	*3c*	
If 15th percentile crossing speed of pedestrians is less than 3.5 ft/s (1.1 m/s), then reduce *3c* by up to 50 percent; otherwise enter *3c*.	3*d*	
If *2a* ≥ *3d*, then the warrant has been met and a traffic signal should be considered if not within 300 ft (91 m) of another traffic signal. Otherwise, the warrant has not been met. Go to Step 4.		

Step 4: Estimate pedestrian delay.		
Pedestrian crossing distance, curb to curb (ft), L	*4a*	
Pedestrian walking speed (ft/s), S_p	*4b*	
Pedestrian start-up time and end clearance time (s), t_s	*4c*	
Critical gap required for crossing pedestrian (s), $t_c = (L/S_p) + t_s$ OR $[(4a/4b) + 4c]$	*4d*	
Major road volume, total both approaches or approach being crossed if median refuge island is present during peak hour (veh/h), V_{maj-d}	*4e*	
Major road flow rate (veh/s), $v = (V_{maj-d}/0.7)/3600$ OR $[(4e/0.7)/3600]$	*4f*	
Average pedestrian delay (s/person), $d_p = (e^{v\,t_c} - v\,t_c - 1)/v$ OR $[(e^{4f \times 4d} - 4f \times 4d - 1)/4f]$	*4g*	
Total pedestrian delay (h), $D_p = (d_p \times V_p)/3{,}600$ OR $[(4g \times 2a)/3600]$ (this is estimated delay for all pedestrians crossing the major roadway without a crossing treatment – assumes 0% compliance). This calculated value can be replaced with the actual total pedestrian delay measured at the site.	*4h*	

Step 5: Select treatment based upon total pedestrian delay and expected motorist compliance.		
Expected motorist compliance at pedestrian crossings in region, Comp = high or low	*5a*	

Total Pedestrian Delay, D_p (from *4h*) and Motorist Compliance, Comp (from *5a*)	**Treatment Category** (see Descriptions of Sample Treatments for examples)
$D_p \geq 21.3$ h (Comp = high or low) OR $5.3\ h \leq D_p < 21.3$ h and Comp = low	RED
$D_p < 5.3$ h (Comp = high or low) OR $5.3\ h \leq D_p < 21.3$ h and Comp = high	ACTIVE OR ENHANCED

Figure 3.6 Pedestrian Safety Crossing Treatments Worksheet 2: Greater than 35 MPH

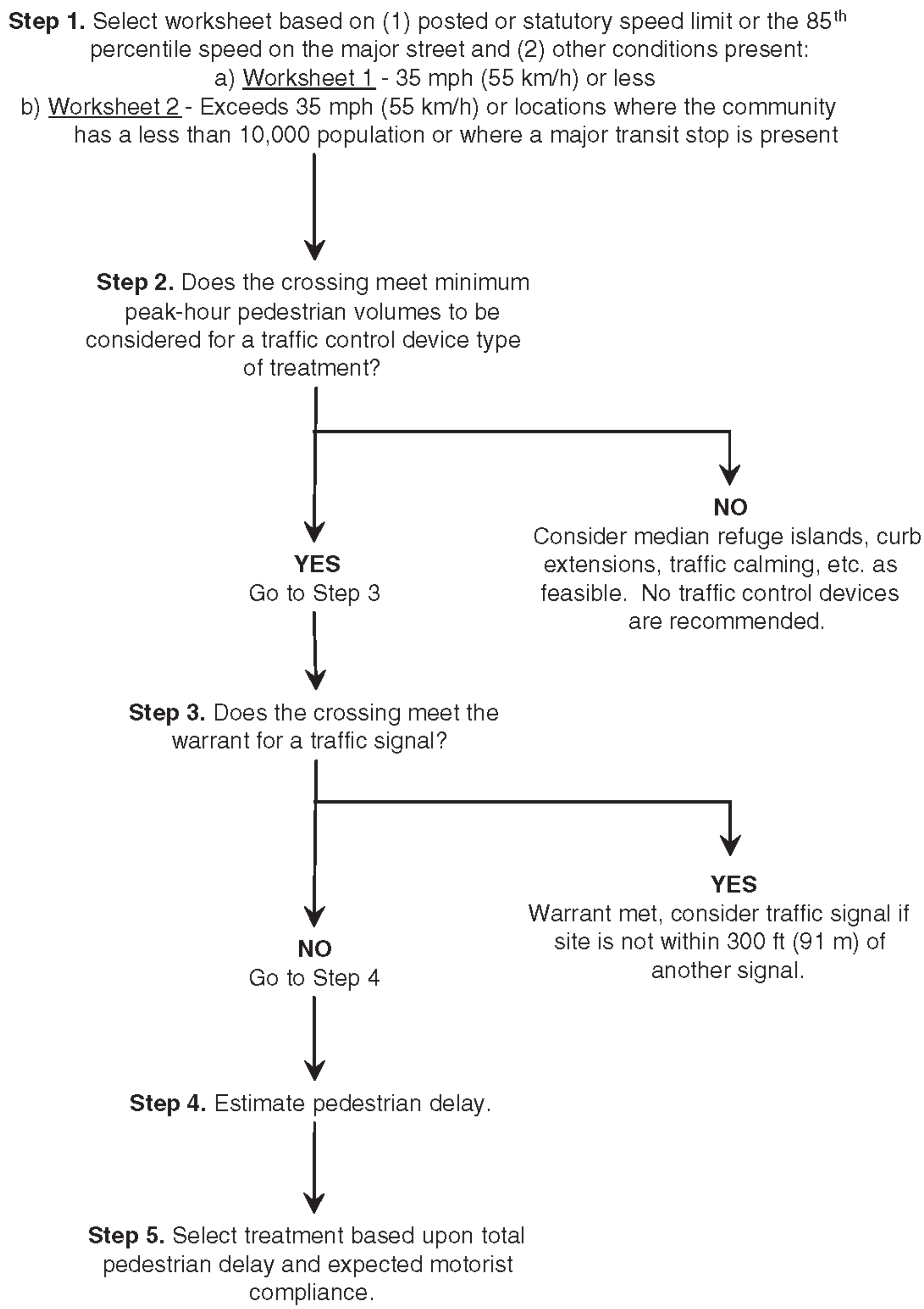
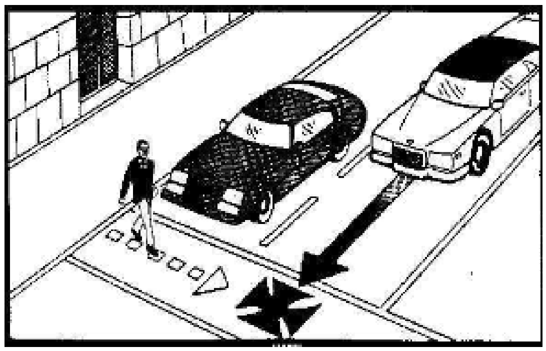


Figure 3.7 Pedestrian Safety Crossing Treatments Flowchart

Results from the study are incorporated into the MUTCD and Highway Capacity Manual (HCM). Some of this information is included in Chapter 8.

Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations [11]

The report is a comprehensive document that covers research into the safety of unmarked versus marked crosswalks. The research recognized that most crossings are unmarked but marked crossings can increase the visibility of pedestrians and alerts motorists to the likely presence of pedestrians. Marked crosswalks are also generally accompanied by crosswalk signage. Marked crosswalks may provide a false sense of security. When there are multiple travel lanes on each approach there is a higher occurrence of crashes due to the multiple threat posed.

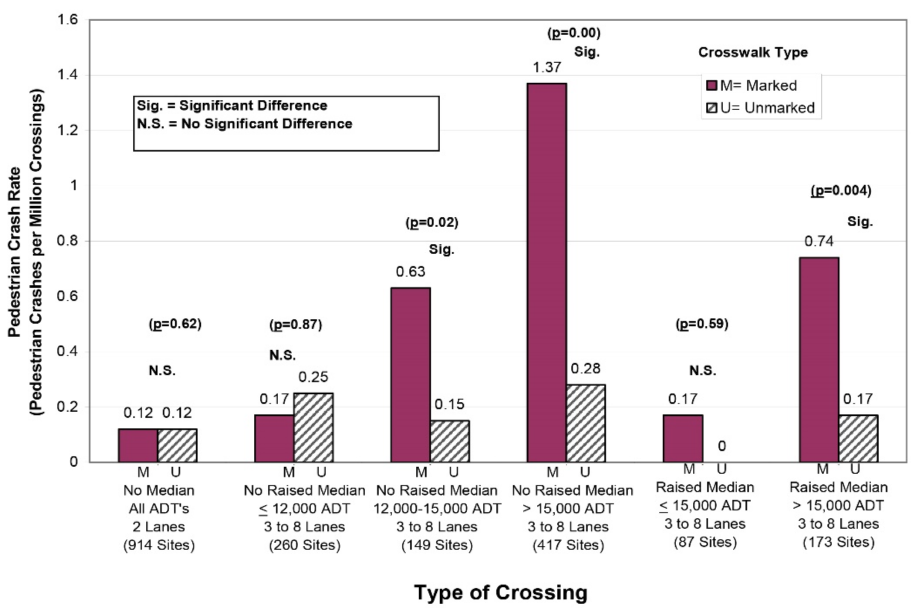


[11]

Figure 3.8 Multiple-Threat Pedestrian Crash Illustration

Sites in the study did not include any traffic-calming treatments or other devices. School crossings were also excluded from the site selection process. As such, the results do not apply to crossings with those attributes.

The research indicates that there is a statistically significant difference in the safety between a marked and unmarked crossing when traffic volume is over 15,000 or over 12,000 without a median under most speeds. [11]



[11]

Figure 3.9 Pedestrian Crash Rate versus Type of Crossing

Based on the research marked crosswalks alone are not recommended at uncontrolled crossing locations on multilane roads (i.e., four or more lanes), where traffic volume exceeds approximately 12,000 vehicles per day (with no raised medians), or approximately 15,000 ADT (with raised medians that serve as refuge areas). The recommendation is based on the analysis of pedestrian crash experience, as well as exposure data and site conditions.

Additionally, marked crosswalks should not be installed alone on two lane roads with ADTs greater than 12,000 or on multilane roads with ADTs greater than 9,000 (with no raised median) to add a margin of safety and/or to account for future increases in traffic volume.

The study also recommends against installing marked crosswalks alone on roadways with speed limits higher than 40 mph based on the expected increase in driver stopping distance at higher speeds. Enhanced crossing treatments (e.g., traffic-calming treatments, traffic and pedestrian signals when warranted, or other substantial improvement) are recommended.

"On two-lane roads and lower volume multilane roads (ADTs less than 12,000), marked crosswalks were not found to have any positive or negative effect on pedestrian crash rates at the study sites. It is recommended that crosswalks alone not be installed at locations that may pose unusual safety risks to pedestrians. Pedestrians should not be encouraged to cross the street at sites with limited sight distance, complex or confusing designs, or at sites with certain vehicle mixes (many heavy trucks) or other dangers unless adequate design features and/or traffic control devices are in place." [11]

The following paragraph includes special consideration:
"At uncontrolled pedestrian crossing locations, installing marked crosswalks should not be regarded as a magic cure for pedestrian safety problems. However, marked crosswalks also should not be considered as a negative measure that will necessarily increase pedestrian crashes. Marked crosswalks are appropriate at some locations (e.g., at selected low-speed, two-lane streets at downtown crossing locations) to help channel pedestrians to preferred crossing locations, but other roadway improvements are also necessary (e.g., raised medians, traffic-calming treatments, traffic and pedestrian signals when warranted, or other substantial crossing improvement) when used at other locations." [11]

Based on the results of the research of pedestrian crossings throughout the United States the report provides a table for where marked pedestrian crossings should be placed based on the cross-street ADT, travel speed, and number of lanes. It is important to recognize that the research indicates where pedestrian crossing markings alone may or may not be sufficient. The research does not indicate where pedestrian crossings with alternative treatments should or should not be located. In all cases, an engineering study should be completed to determine whether a location is suitable or not, and if additional pedestrian crossing treatments are justified. The table and additional safety considerations are included in Chapter 5.

HCM 2010, Highway Capacity Manual [12]

The Highway Capacity Manual (HCM) provides the methodology for evaluation of pedestrian crossings on an operational basis. The HCM provides an analysis methodology for both signalized and unsignalized crossing locations. This includes an analysis to determine delay and service levels at pedestrian crossings at for pedestrians. The focus of this study is on uncontrolled crossings (i.e. crossings in which vehicle traffic is not controlled by a signal or stop sign and/or pedestrian traffic is not controlled by a signal). This methodology is included in Chapter 6 of this report.

Chapter 4
Data Collection and Field Review

The first step in understanding the pedestrian needs at a potential pedestrian crossing location is completing a review of the location and adjacent facilities. A Data Collection Field Review Worksheet is provided for the data collection at the end of this chapter. The Field Data Review should consider the following elements and information to be collected.

Geometrics

Crossing Length

The length across the roadway at the crossing location affects how long a pedestrian is exposed to conflicting motorist traffic. A shorter pedestrian crossing length is preferred. The crossing length (L) is measured from curb face to curb face and it is the total length a pedestrian is exposed to conflicting traffic. In cases where there is a median, two separate crossing lengths are measured, as shown in Figure 4.2.

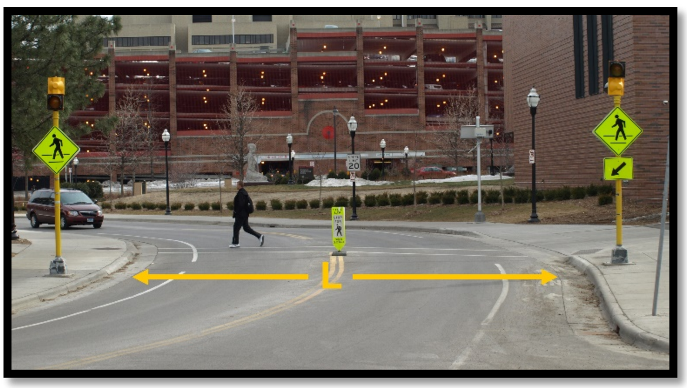


Figure 4.1 Pedestrian Crossing Length (1 of 2)

Figure 4.2 Two-Stage Pedestrian Crossing Length

Figure 4.3 Pedestrian Crossing Length (2 of 2)

Median Width

The median can provide for a staged crossing where a pedestrian only needs to cross one side of the street at a time. A median provides a refuge space for pedestrians. A median should be of sufficient size to handle the pedestrians using the crossing. In most cases a sufficiently sized raised pedestrian median refuge includes a minimum median width of 6’ and a minimum 5’ crossing width. This would indicate that there is a sufficient median refuge for pedestrians to allow for a staged crossing, but smaller medians may be sufficient based on the type of pedestrians using the crossing. A wider median is preferred by pedestrians. In the case of smaller medians, the majority of pedestrians would use a different adjacent crossing location that provides close to equal travel time. The median width (W) is measured from curb face to curb face.

Figure 4.4 Median Width (1 of 2)
ADA Compliant

Figure 4.5 Median Width (2 of 2)
Not ADA Compliant

Another consideration is that a minimum 4’ x 4’ landing area must be provided at all pedestrian refuges as consistent with Americans with Disabilities Act (ADA) requirements. With the addition of truncated domes (domes usually come in 2’ by 2’ squares) to separate walking spaces from spaces designated for both motor vehicles and pedestrians, this essentially would require a minimum 8’ wide median instead of the 6’ wide median as the minimum width. Best practice is to make the median crossing with the same width as the crosswalk markings. Measure the width of the median and the width of the crossing through the median.

Crosswalk Width

Another important measurement is the crosswalk width. While crosswalks are typically six to eight feet wide, the effective crosswalk width may actually be different. The effective crosswalk width (W_c) is the narrowest spot on the entire crossing length. This can be dictated by a number of different aspects including the truncated dome width, the crosswalk marking width, median noses or other obstructions, and/or the median opening width. Striping outside of the crossing width is essentially unusable space when considering the needs of all pedestrians. That being said, the effective width may be wider than the truncated domes and/or pedestrian ramp if determined to be appropriate based on the crossing users, such as in urban downtown settings with significant pedestrian users that do not use the pedestrian ramp and can effectively use the entire crossing width. A review of actual pedestrian use of the crossing is recommended to verify.

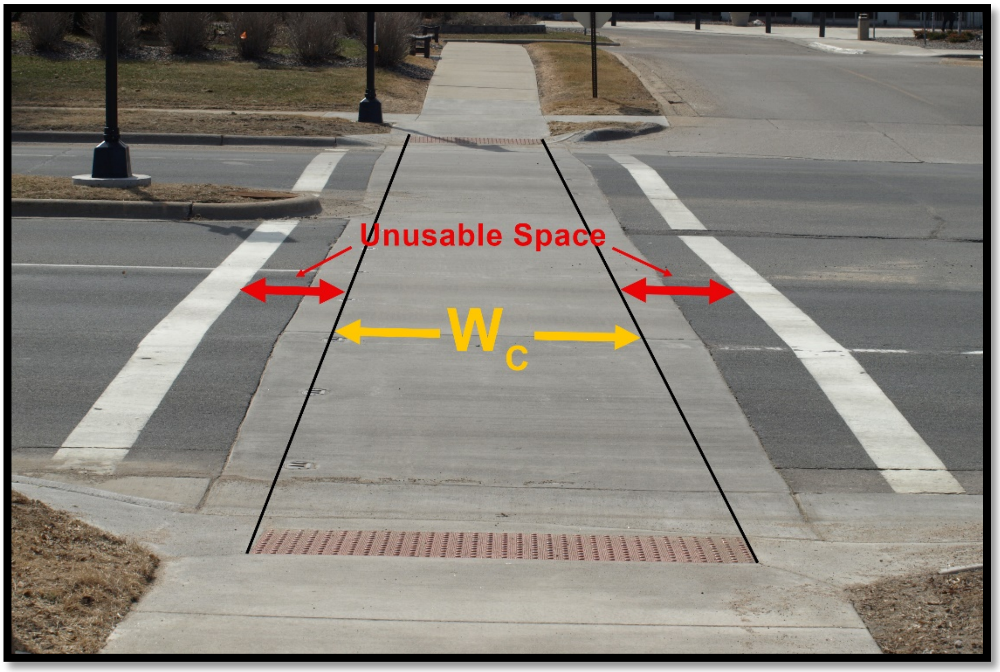


Figure 4.6 Effective Crosswalk Width (1 of 2)

Figure 4.7 Effective Crosswalk Width (2 of 2)

Curb Ramps

The MN MUTCD states that “Crosswalk markings should be located so that the curb ramps are within the extension of the crosswalk markings. Detectable warning surfaces mark boundaries between pedestrian and vehicular ways where there is no raised curb. Detectable warning surfaces are required by 49 CFR, Part 37 and by the Americans with Disabilities Act (ADA) where curb ramps are constructed at the junction of sidewalks and the roadway, for marked and unmarked crosswalks. Detectable warning surfaces contrast visually with adjacent walking surfaces, either light-on- dark, or dark-on-light. The "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)" contains specifications for design and placement of detectable warning surfaces.” [2], [13]

Figure 4.8 Curb Ramp Elements

Figure 4.9 Detectable Warning Surfaces (Truncated Domes)

Access to the crossing by all non-motorized traffic must be provided if the crossing is to be used by pedestrian traffic. This includes providing curb ramps for access to the crossing location. [13] Curb design acceptable for all users is a course unto itself and the details of it are beyond the scope of this study. Guidance on acceptable curb ramp design and parameters are included on the MnDOT Accessibility Webpage. [13]

Curb ramp locations and directionality should be noted. Note where there are truncated domes. Truncated domes do not have to be directional with the crosswalk.

Figure 4.10 Curb Ramps with Landing and No Truncated Domes [14]

Figure 4.11 Curb Ramp with Landing and Truncated Domes [14]
Eagan

Curb ramps provide equal access to all users. Pedestrian curb ramps are required for all pedestrian crossing locations. Determine if curb ramps are provided. Are they ADA compliant, i.e. include truncated domes, maximum 5% grade if there is no change in direction or maximum 8.3% grade with a 4’x4’ landing?

Roadway Speed

The posted speed limit or 85th percentile speed of the crossed roadway affects the stopping sight distance of vehicles and the safety of the crossing. The higher the vehicle speed, the higher the probability for a fatal crash. This effect is as shown in the following tables, based upon research completed.

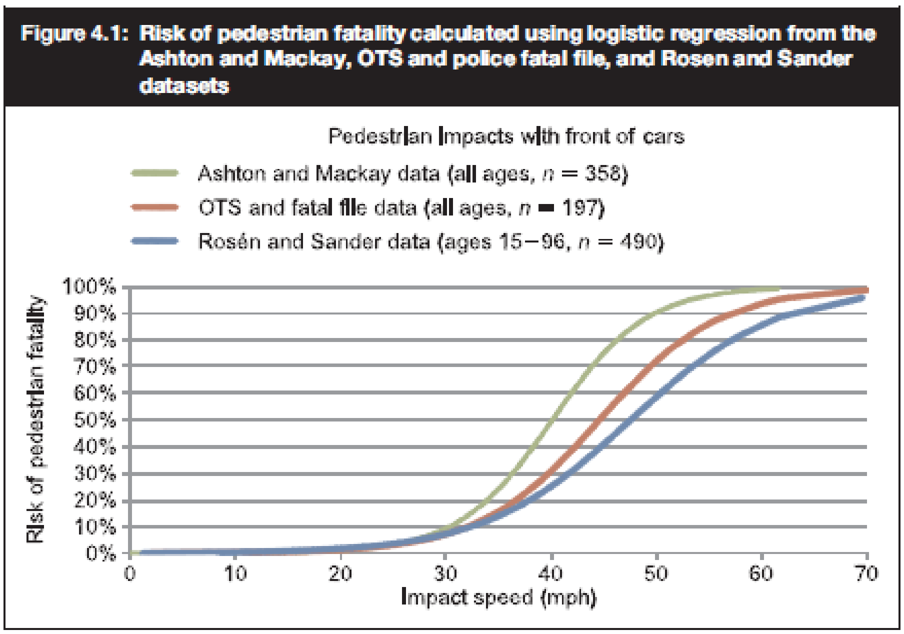


Figure 4.12 Risk of Pedestrian Fatality Based on Vehicle Impact Speed [15]

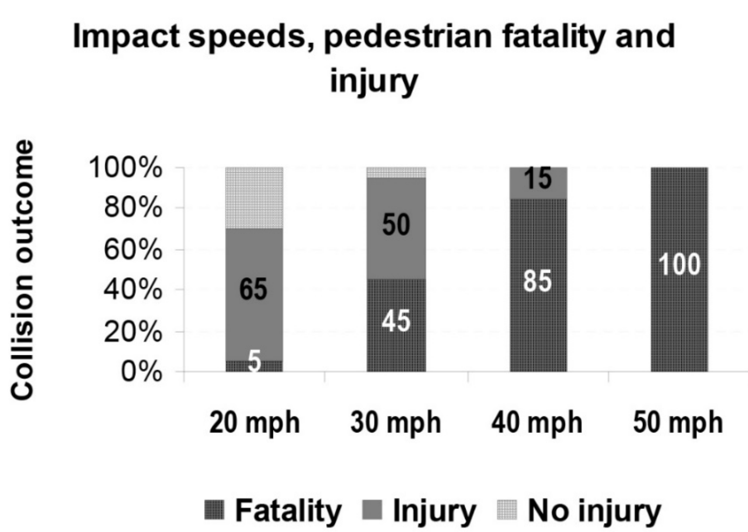


Figure 4.13 Vehicle Impact Speed and Pedestrian Severity [16]

As indicated by the above, slower vehicle speeds have been shown to reduce the possibility of a fatal crash. A pedestrian crossing location that is in an area where speed limits are lower is preferable to placing a crossing on a higher speed roadway segment due to the higher incidence of a fatality. The speed of a vehicle directly impacts the sight distance needed and the braking time of a vehicle. The roadway design speed (S) is used to determine the stopping sight distance. The speed should be the 85th percentile speed of the roadway being crossed. In the absence of collected speed data, it is assumed that the 85th percentile speed is equal to the speed limit.

Average Walking Speed

The speed of pedestrians using a crossing can have a direct impact on pedestrian sight distance and the Highway Capacity Manual (HCM) Level of Service. The default for pedestrian walking speed is 3.5 ft/s, unless field data on average speed can be collected at the actual crossing. Crossings that serve a significant volume of children, an older population, or people with disabilities may require a slower walk time while crossings with a significant volume of runners and/or teens may have faster walk times. It may be important to determine walking speeds depending on pedestrian composition and traffic volume at different times of day.

Although average walking speed is used in the calculations, the 3.5 ft/s walking speed dictated in the MN MUTCD and other sources, is actually the 15th percentile speed and not the average. This ensures that 85% of pedestrians are able to cross faster than the walking speed accounted for or as in the case of a signalized crossing, ensure that 85% of pedestrians using a crossing are able to get across in the time allotted during a flashing don't walk. Examples from real-world locations in Minnesota are included in Chapter 6, Table 6.1 for a comparison.

Roadway Curvature

The crossing location should be located outside of horizontal and vertical curves to provide adequate stopping sight distance to the crossing location. Motorist attention to the curvature of the roadway can detract motorist attention to any potential crossing location and a pedestrian using the crossing.

Possible obstructions include:

- buildings,
- trees,
- hills, and/or
- landscaping.

Is the crossing location within a horizontal or vertical curve? If so, additional considerations are needed to ensure adequate stopping sight distance.

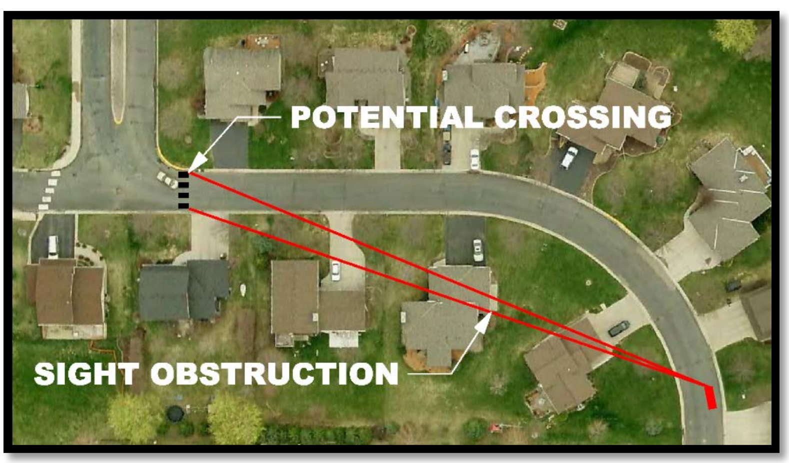


Figure 4.14 Horizontal Curvature Obstruction

Sight Distance

Stopping Sight Distance

As defined by AASHTO, the Stopping Sight Distance is the length of roadway ahead that is needed for stopping and includes both brake reaction time and braking distance. [6]

$$SSD = 1.47Vt + 1.075\frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \pm G\right]}$$

Where:
SSD = Stopping Sight Distance
V = roadway speed (mph)
t = brake reaction distance, 2.5 s
a = deceleration rate, ft/s^2
G = grade, rise/run, ft/ft

Default values may be used for brake reaction distance and deceleration rate:
t = 2.5 s from AASHTO
a = 11.2 ft/s^2 from AASHTO

All pedestrian crossings shall be placed to provide adequate stopping sight distance. Additional features or roadway geometry changes may be needed to provide adequate sight distance.

Pedestrian Sight Distance

Another consideration is the distance in which a pedestrian is able to see a conflicting vehicle and determine if they are able to cross the pedestrian crossing location before the vehicle is at the crossing. This is especially important where there is an absence of warning signs, markings, or other pedestrian crossing treatments. While motorists are required to stop for pedestrians, the pedestrian sight distance takes into consideration when vehicles do not tend to yield right-of-way and also accounts for the pedestrian needs.

Pedestrian Crossing Sight Distance is the length of roadway that must be seen from the crossing that is needed for crossing the roadway in the absence of vehicle yielding and includes both pedestrian start-up and clearance times and the time to cross the roadway.

$$PedSD = 1.47V\left(\frac{L}{S_p} + t_s\right)$$

Where:
$PedSD$ = Pedestrian Crossing Sight Distance
V = roadway speed (mph)
L = Crossing distance (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)

Default values may be used for pedestrian walking speed and pedestrian start-up and end clearance time:

S_p = 3.5 ft/s from MN MUTCD

t_s = 1.5 s from HCM 2010

Traffic and Pedestrian Data

<u>Traffic Volume</u>

The volume of traffic on the roadway directly affects the available gaps for pedestrians to cross the roadway. Measure the traffic volume in 15-minute increments on the roadway to be crossed. The volume includes all traffic across the crossing location.

<u>Pedestrian Volume</u>

The volume of pedestrians using the crossing location can indicate if the pedestrian crossing is necessary or if additional treatment options may be needed. Measure the pedestrian crossing volume in 15-minute increments on the roadway to be crossed.

In most cases, the daily pedestrian volume will not be collected, but can be an indicator of the crossing location use throughout the day.

Additional Site Characteristics

<u>Lighting</u>

Lighting is important in providing a guide to drivers and pedestrians by lighting both the pedestrian using the crossing and the pedestrian pathway across a roadway. It also provides a visual cue to drivers that there is an intersection or pedestrian crossing location.

Lighting should be placed to provide positive contrast to pedestrians using a crossing. This includes lighting pedestrians from the front other than providing lighting behind the pedestrian. In most cases this means that lighting should be placed prior to the crossing location for each direction of traffic. While this is not possible for all locations, it is especially important on wider roadways with or without medians.

Example lighting configurations to provide positive contrast are provided on the next page.

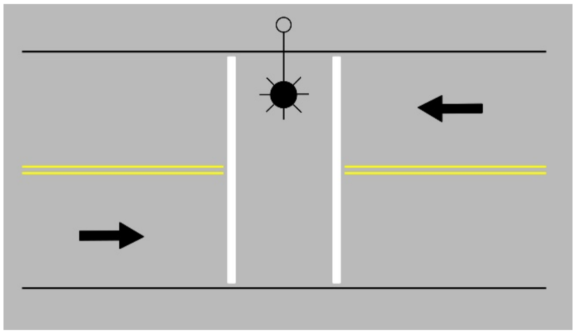


Figure 4.15 Lighting Placement (1 of 5)
Two Lane Mid-Block Crossing

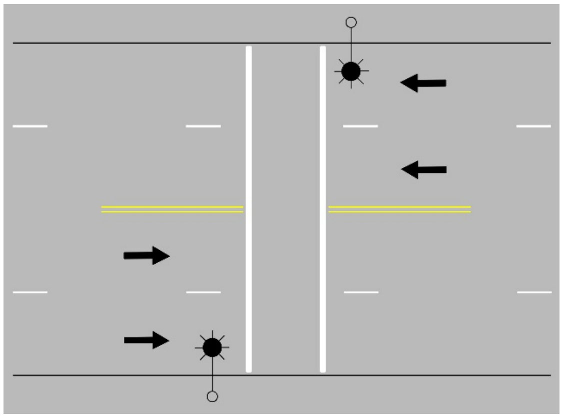


Figure 4.16 Lighting Placement (2 of 5)
Multi-Lane or Long Mid-Block Crossing

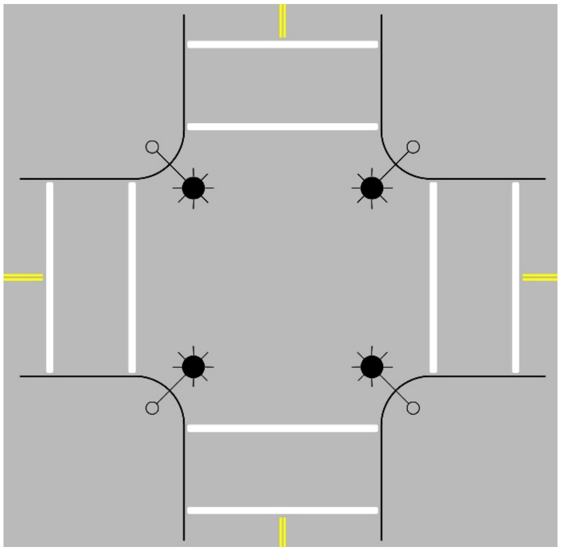


Figure 4.17 Lighting Placement (3 of 5)
Intersection: Traditional

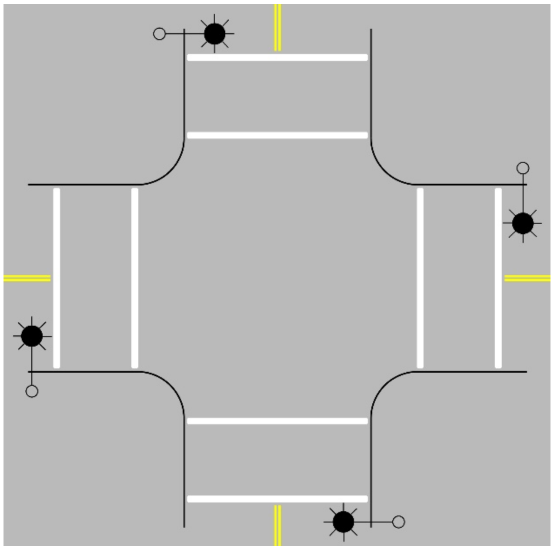


Figure 4.18 Lighting Placement (4 of 5)
Intersection: Pedestrian Crossing Focused

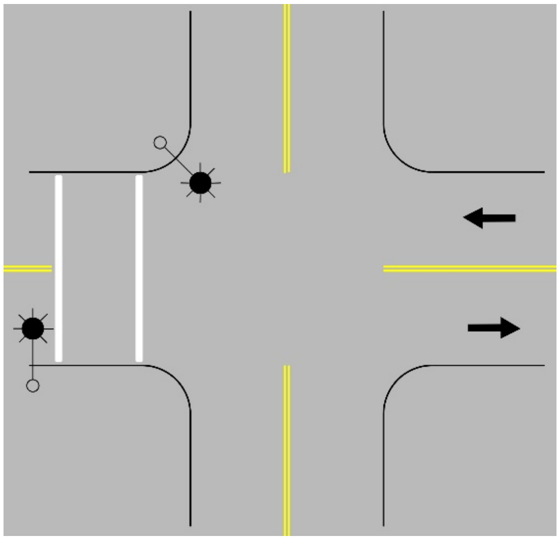


Figure 4.19 Lighting Placement (5 of 5)
Intersection: Pedestrian Crossing Focused on One Leg

Is there continuous street lighting, intersection lighting, and/or pedestrian level lighting on pedestrian facilities within the area? Note the placement of the lighting to determine if positive guidance is provided for crossing locations.

Depending on the location, it may be important to field verify that the entire crossing is lighted, especially if there is a high probability of pedestrians using the crossing during dark/nighttime hours. For wide roadways (more than two approach lanes in each direction) or roadways with medians it may be advantageous to evaluate the lighting levels across the crossing. The most important aspects of this evaluation is to ensure that there are no dark spots along the crossing and that the lighting is moderately uniform. Lighting evaluation and guidance should follow the AASHTO Roadway Lighting Design Guide. Pedestrian lighting of crossings should meet the requirements of the roadway being crossed. [17]

Crosswalk Pavement Markings

Crosswalk pavement markings alert and provide visual guidance to drivers and roadway users that there is a designated crossing location and to expect pedestrians. Crosswalk pavement markings also indicates to pedestrians that a specific location is preferred over other unmarked locations along the same roadway. In most cases a marked crosswalk location will also include appropriate crosswalk signage.

The MN MUTCD defines the appropriate marking sizes that must be followed for installation of a marked crosswalk. “When crosswalk lines are used, they shall consist of solid white lines that mark the crosswalk. They shall not be less than 6 inches or greater than 24 inches in width. If transverse lines are used to mark a crosswalk, the gap between the lines should not be less than 6 feet. If diagonal or longitudinal lines are used without transverse lines to mark a crosswalk, the crosswalk should be not less than 6 feet wide. Crosswalk lines, if used on both sides of the crosswalk, should extend across the full width of pavement to the edge of the intersecting crosswalk to discourage diagonal walking between crosswalks.” [2]

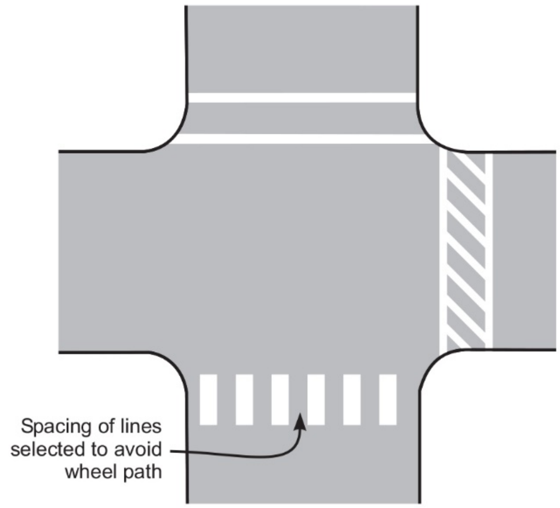


Figure 4.20 Crosswalk Marking Examples [2]

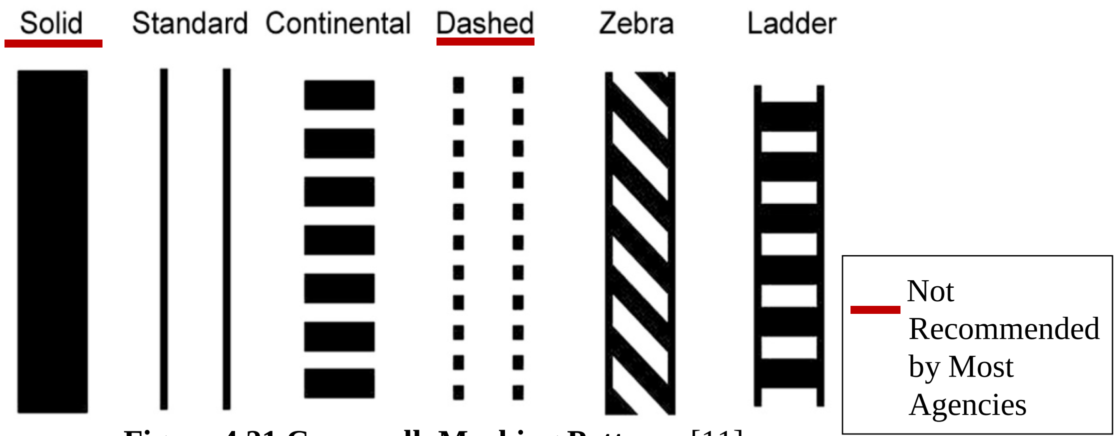


Figure 4.21 Crosswalk Marking Patterns [11]

High visibility crosswalk markings include: Continental, Zebra, and Ladder. Solid and Dashed markings are not recommended. Solid can result in very slippery surfaces while dashed can be difficult for motorists to see. Markings should be in good to excellent condition and highly visible to approaching traffic. The condition of the markings is important to determine if they should be replaced or not.

- Excellent: No visible wear to markings, “like new”
- Good: Minimal wear to markings
- Fair: Extensive wear in places but can generally be seen by approaching vehicles, replacement may be needed
- Poor: Extensive wear, difficult to determine if the crossing is marked, immediate replacement recommended

Verify if the pedestrian crossing is currently marked. What is the condition of the markings? Are the markings easily defined? Do they need replacement? What is the current crosswalk marking pattern? If at an intersection, which legs are marked? For additional information on crosswalk pavement markings see the MN MUTCD and MnDOT Traffic Engineering Manual (TEM).

Figure 4.22 Standard Crosswalk

Figure 4.23 Continental Crosswalk

Signing

Pedestrian warning signs may be used to alert road users in advance of a pedestrian crossing location where unexpected entries into the roadway might occur or where shared use of the roadway by pedestrians might occur. They may be placed in advance of a crossing location and/or at the crossing location. “Non-vehicular signs should be used only at locations where the crossing activity is unexpected or at locations not readily apparent.” [2]

The MN MUTCD dictates the acceptable signing to be used in conjunction with a pedestrian crossing. Signing may or may not be installed in conjunction with crosswalk markings. Signing shall follow the design and placement as stated in the Minnesota Manual on Uniform Traffic Control Devices. Additional information on signing is included in Chapter 3.

Is the crossing currently signed with the appropriate warning signs at the crossing? Any warning signs in advance of the crossing? At what distance are the signs from the crossing?

Figure 4.24 Pedestrian Crossing Warning Sign (W11-2)
Placed at the Crossing Location

Figure 4.25 Pedestrian Crossing Warning Sign plus In-Road Signs

Figure 4.26 Advanced Pedestrian Crossing Warning Sign

Figure 4.27 School Crossing Warning Sign

Enhancements

The presence of pedestrian crossing enhancements at the location being studied should be noted. This includes any activated crossing features, pedestrian control devices, and/or traffic calming enhancements.

Adjacent Facilities

The presence of other crossings parallel to the location being studied should be recognized. This includes both marked and unmarked locations that may be used by pedestrians. It is especially important to determine where the nearest currently marked crossing of the same street or highway is located. Evaluation may determine that another crossing may be more appropriate and serve the same origins and destinations with little or no additional delay imposed on the pedestrian.

- How far is the nearest adjacent marked crossing?
- What facilities are present at the nearest adjacent marked crossing?
- Does the crossing have warning signs, a flasher system, etc. that may make it an easier crossing to use?
- How far is the nearest all-way stop, roundabout, or traffic signal? The presence of these types of traffic control in conjunction with a pedestrian crossing provide a different level of pedestrian safety and recognition of pedestrian movements by motorists.
- Could another location serve the same pedestrian crossing movement? It is important to understand if another crossing location nearby can serve the same pedestrian movements

that can be provided at the studied location. If there is missing sidewalk or connection between the locations, the same movements may not be served effectively at another location.

- Could another location serve the movement more effectively? This requires a determination of the origins and destinations near the study site. Another location may more effectively connect the origins and destinations that is not readily apparent. What is the most direct route between origins and destinations? If route is actually shorter, determining why this route is preferred is an important aspect to answer.
- If there is a nearby pedestrian crossing facility that can serve the same movements, the crossing location being studied may not be needed. In some cases, an existing pedestrian crossing may not serve the pedestrian movements of the area and should be moved to a more appropriate location. The other location may actually provide a shorter travel time when considering the time waiting to cross.

Site Sketch or Aerial

Concurrent with a field review, a site sketch or aerial view and notes on the potential crossing location should be completed. This brings context to the location and helps to provide a record of what is currently in the field. It may also provide justification for whether changes may or may not be needed.

Specific items to note on the sketch or aerial if not readily apparent in the picture.

- Pavement Markings: The current pavement markings at the crossing location should be recorded. This includes the presence of crosswalk markings, edge lines, center lines, lane lines, stop lines, or any other markings.

- Signing: This includes signing at and near the crossing including pedestrian signs and any other signs, as the location of signing may impact how drivers view the area. Reduced signing in the area reduces visual clutter, making pedestrians easier to see.

- Lighting: Note the location of lighting to check positive guidance. If needed, lighting levels may also be checked if mounting height and fixtures are known.

- Curb Ramps and Truncated Domes: curb ramp locations and directionality should be noted. Note where there are truncated domes and general directionality of the domes.

- Parallel and nearby crosswalk locations: Measure distances to nearest crosswalk locations that serve the same roadway being crossing.

- Adjacent Intersections with All-Way Stop, Signal, or Roundabout: Measure distances to nearest intersection with any of the above traffic controls.

- Origins and Destinations: Review the area for origins and destinations to determine the need for the crossing at the location. All marked crossings should serve a needed origin-destination connection. Typical origins and destinations of importance include:
    - Bus stops to businesses and residences
    - High density residential to bus stops and commercial/retail
    - Hospitals and medical centers to bus stops and parking
    - Retirement communities to bus stops and commercial/retail
    - Schools/colleges/universities to residential housing and parking
    - Parks to residences
    - Recreational/community centers to residences and parking
    - Theatres and museums to parking
    - Trails to parks and other trails
    - Commercial/retail space to parking

Look at origins and destinations that are connected, such as parking on one side of a roadway and an office building or restaurant on the other side. Note the location of office building and restaurant entrances.

It is important to remember that pedestrians will take the shortest route if at all possible. This relates to understanding why a route is being used, especially when there are alternatives available that may actually be safer and provide less delay. In some cases existing crossings may not actually be placed where pedestrians are using them if the understanding of origins and destinations has changed over time or is incorrect to begin with.

LRRB

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	______	Date:	______
City, State:	______	Scenario:	______
Reviewer(s):	______	Agency:	______
Project #:	______	ID #:	______

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances. — Crossing 1 ____ ft. / Crossing 2 ____ ft.

Median: width of median at crossing location ____ ft.

Crossing Width: effective crosswalk width ____ ft.

Raised Median Available?	☐ Yes	☐ No
ADA Compliant Median Available (minimum 4' x 4' landing)?	☐ Yes	☐ No
Curb Ramps Available?	☐ Yes	☐ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?	☐ Yes	☐ No

Speed: Posted or 85th percentile speed ____ mph

Roadway Curvature and Sight Distances: Average walking speed ____ ft/s

Is the crossing location within a horizontal or vertical curve? ☐ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:		Daily		pedestrians:		Daily	
AM Peak	Hourly		Pk 15-min		Hourly		Pk 15-min	
PM Peak	Hourly		Pk 15-min		Hourly		Pk 15-min	

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☐ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☐ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern? ______

Signing: Currently signed at crosswalk? ☐ Yes ☐ No

Currently signed in advance of crosswalk? ☐ Yes ☐ No

Distances? direction 1 ____ ft. direction 2 ____ ft.

Enhancements: What enhancements are currently at the crossing location? ______

Adjacent Facilities: Distance to nearest marked crosswalk? ____ ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? ______

Distance to nearest all-way stop, roundabout or signalized intersection ____ ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☐ No

Could another location serve the the movement more effectively? ☐ Yes ☐ No

Developed by Bolton & Menk, Inc. in coordination with the Local Road Research Board. Worksheets made without charge and under no circumstances shall be sold by third parties for profit.

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Figure 4.28 Data Collection Worksheet (Page 1)

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied

Notes: ____________________

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Page 2 of 2

Figure 4.29 Data Collection Worksheet (Page 2)

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Chapter 5
Safety Evaluation

The Safety Effects of Marked Versus Unmarked Crosswalks at Uncontrolled Locations by the Federal Highway Administration provides extensive research into safety considerations of crosswalks through an evaluation of field collected and crash data from sites throughout the United States.

A table for where marked pedestrian crossings should be placed and appropriate enhancements is based on the cross-street ADT, travel speed, and number of lanes as shown on the following page.

Table Definitions

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

It is important to recognize that the research indicates where pedestrian crossing markings alone may or may not be sufficient. The research does not indicate where pedestrian crossings with alternative treatments should or should not be located. In all cases, an engineering study should be completed to determine whether a location is suitable or not, and if additional pedestrian crossing treatments are justified. [11]

Table 11. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000-15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.

*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = **Candidate sites for marked crosswalks** . Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more indepth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

In some situations (e.g., low-speed, two-lane streets in downtown areas), installing a marked crosswalk may help consolidate multiple crossing points. Engineering judgment should be used to install crosswalks at preferred crossing locations (e.g., at a crossing location at a streetlight as opposed to an unlit crossing point nearby). While overuse of marked crossings at uncontrolled locations should be avoided, higher priority should be placed on providing crosswalk markings where pedestrian volume exceeds about 20 per peak hour (or 15 or more elderly pedestrians and/or children per peak hour).

Marked crosswalks and other pedestrian facilities (or lack of facilities) should be routinely monitored to determine what improvements are needed.

[11]

Table 5.1 Recommendations for Installing Marked Crosswalks at Uncontrolled Location

Chapter 6
Operational Evaluation

There are two primary methods in determining how the traffic on a roadway affects how long a pedestrian waits to cross the roadway and determines if it is even possible for a pedestrian to cross the roadway at the crossing location given actual traffic levels.

- A gap study is used to determine the number of gaps of adequate size to allow for a pedestrian to cross the roadway at a particular location.
- A Level-of-Service (LOS) evaluation is used to determine how long a pedestrian waits on average and equates this with a service level. The longer a pedestrian is anticipated to wait, the more unacceptable the wait becomes and there is a higher probability of a pedestrian completing a crossing maneuver when it is not safe to do so.

Data collected in the field is used to provide essential information in the evaluation of a pedestrian crossing location.

Gap Study

A gap study is used to determine the number and size of gaps that are available to cross the roadway. The length of the gaps is used to determine if there are gaps of adequate size between vehicles to safely and effectively provide enough time for pedestrians to cross the roadway. Gap studies require the collection of the time between vehicles and can be quite time intensive. Additionally, it is recognized that while traffic levels are different depending on the hour of the day it also does change from day to day and the gaps collected on one day may be different than another depending on the facility.

The gaps that need to be collected are the gaps that are available at a crossing location. This includes not only determining the gap between vehicles, but the actual gap in which the crossing location is not impacted by a vehicle. Essentially this means accounting for the length of the vehicle by determining the time the actual crossing does not have a vehicle on it. On roadway crossings of similar volume, a roadway with a higher volume of truck traffic usually results in shorter gaps due to the longer vehicles.

There are essentially three methods for collecting gap data.

1. Traffic tube counters: counters must be able to provide intervals of at least one second. This method requires that all calculations be rounded up to the nearest one second. This also does not account for the length of vehicles. To mitigate the unknowns, vehicle classification counts are recommended to determine the number of trucks in the traffic stream and account for the average vehicle length that can also affect the actual gap available.
2. Count Boards: Most manual count boards provide the functionality to do gap studies. This provides a very accurate count of the gap length to tenth of a second.

3. Stopwatch: A stopwatch can be used to also determine the gaps between vehicles but requires that the times be transferred manually. The inclusion of stopwatch features into mobile phones and other electronic devices can include ways to more effectively record the gap times.

The collected gaps are then used to compare against how long it takes a pedestrian to cross the roadway. The adequate pedestrian crossing time or critical headway (t_c) includes:

1. Start-up and end clearance time (t_s): The time for a pedestrian to make a decision that there is an adequate gap and step onto the roadway plus the time for pedestrians to clear the roadway after crossing. The end clearance time is zero if there is a shoulder on the roadway being crossed. The end clearance is provided to ensure that there is some time between a pedestrian and a vehicle as a pedestrian completes the crossing maneuver.
2. Walking time (t_w): The time for a pedestrian to actually cross the roadway. This is determined by dividing the length of the crossing by the crossing speed. Observed pedestrian walking speed should be collected. In the absence of collected data a standard pedestrian walking speed is 3.5 feet per second, consistent with the pedestrian walking speed used in the Minnesota Manual on Uniform Traffic Control Devices.

$$t_w = L / S_p$$

where:
t_w = pedestrian walking time (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s), default = 3.5 ft/s [2], [10]

$$t_c = t_s + t_w$$

where:
t_c = critical headway (s)
t_s = pedestrian start-up and end clearance time (s)
t_w = pedestrian walking time (s)

The 2010 Highway Capacity Manual provides a default pedestrian start-up and end clearance time of 3 seconds in the absence of field collected data. [12]

The adequate gap for crossing the roadway is equal to the crossing time. The crossing location should also be checked to ensure that a pedestrian is able to see a vehicle to provide the crossing time. The pedestrian sight distance required is equal to the crossing time divided by the 85th percentile travel speed along the roadway.

$$PedSD = 1.47 * S * t_c$$

where:
PedSD = pedestrian sight distance (ft)
t_c = critical headway (s)
S = 85th %ile speed of the roadway being crossed or speed limit (mph)

Level of Service Study

A level of service analysis uses the methodology presented in the 2010 Highway Capacity Manual (HCM) to evaluate the potential delay to a pedestrian to cross at an unsignalized or uncontrolled crossing location. An advantage of this methodology over the gap study is that it provides a basis for when the wait becomes too long for a pedestrian and risk-taking is increased. It also uses the traffic volume and number of lanes to be crossed to determine the probability for a delayed crossing to come up with an average delay experienced at the crossing. The LOS methodology can also use yielding data to determine the effects of crossing treatments.

The information presented here is a summary of the process presented in the HCM. The HCM is the official document which provides all of the equations and methodology that is presented within this section of the manual. This manual is not meant to be a replacement of the manual but expands upon the information presented and presents it within the context of a step in the evaluation process of unsignalized and uncontrolled pedestrian crossings.

The Level-of-Service methodology follows six essential steps.

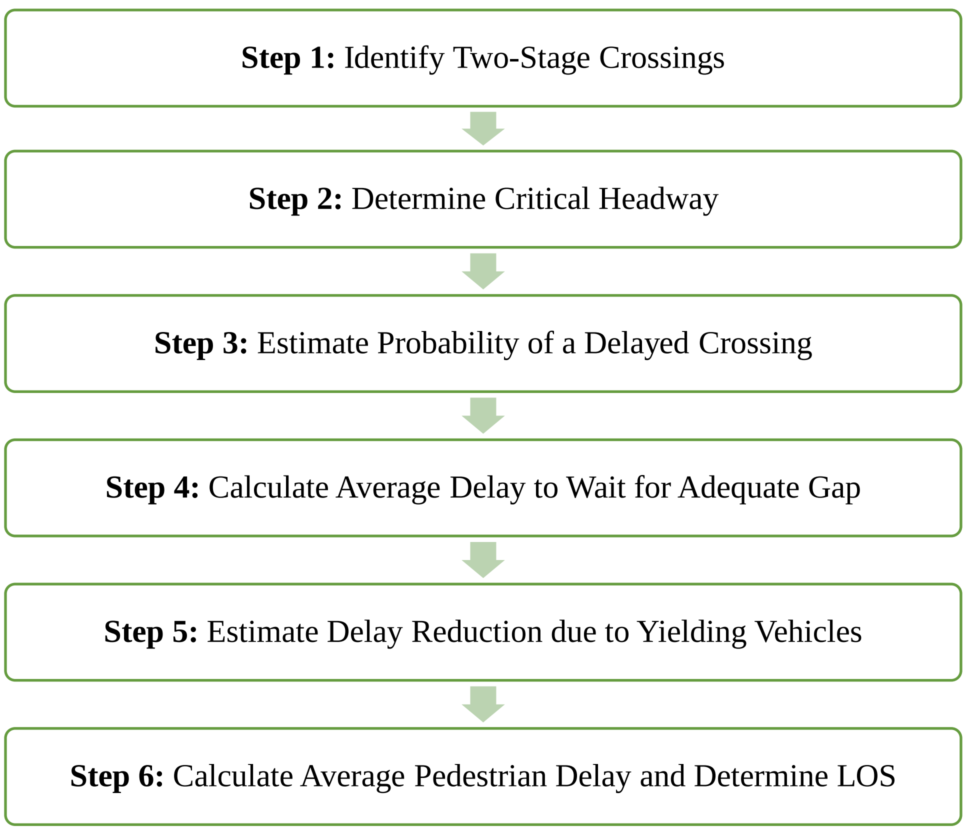

Figure 6.1 Level of Service Methodology [12]

Step 1: Identify Two-Stage Crossings

A two-stage pedestrian crossing is a crossing that can be completed in two stages as a pedestrian crosses a roadway. A two-stage crossing is usually provided through the use of a raised median that separates the crossing into two or more stages. A two-stage crossing most commonly splits the two directions of traffic so a pedestrian crossing the roadway only has to account for one direction of traffic at a time. [12]

Considerations

Is there a raised pedestrian median refuge available? If the crossing is defined as a two-stage crossing, each stage of the crossing is to be calculated separately through each of the subsequent steps.

A raised pedestrian median refuge should be of sufficient size to accommodate the pedestrians that are expected to use the crossing. In evaluation of a two-stage crossing, if a currently raised median is being used as a stop over during a crossing, it can be evaluated as a two-stage crossing. If the majority of pedestrians are crossing in one stage, it is a one stage crossing. In most cases, the minimum median width is 6’ with a minimum 5’ crossing width for a two-stage crossing. This indicates that there is a sufficient median refuge for pedestrians to allow for a two-stage crossing for most pedestrians. Best practice is to provide a 6’ wide crossing width to match the width of the pavement markings.

Another consideration is that a minimum 4’ x 4’ landing area should be provided at all pedestrian refuges as consistent with Americans with Disabilities Act (ADA) requirements. With the addition of truncated domes (domes usually come in 2’ by 2’ squares) to separate walking spaces from spaces designated for both motor vehicles and pedestrians, this essentially could require a median that is 8’wide instead of the 6’ wide median as defined above.

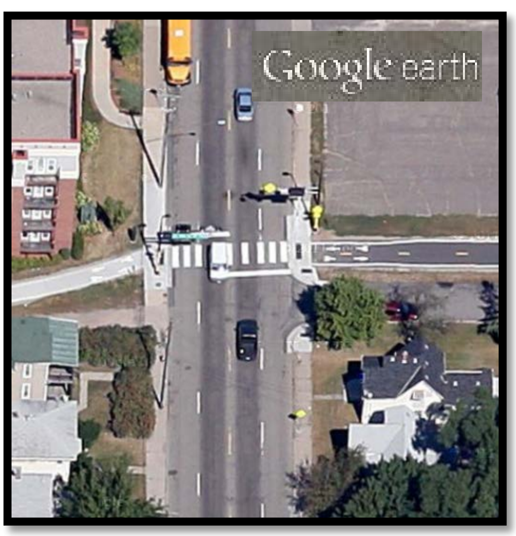

Figure 6.2 One-Stage Crossing [14]
Minneapolis

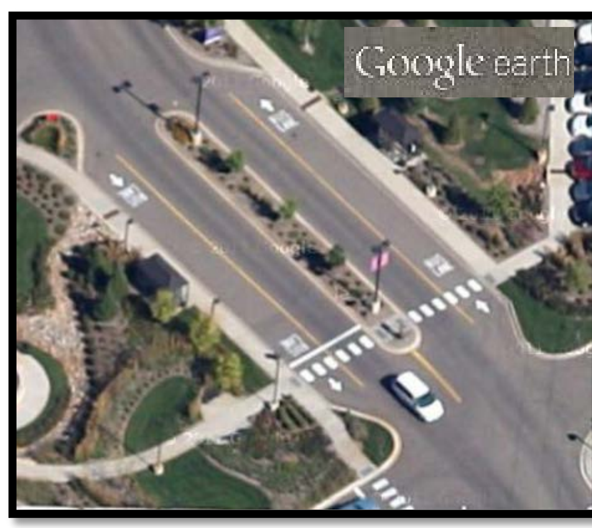

Figure 6.3 Potential Two-Stage Crossing [14]
St. Louis Park

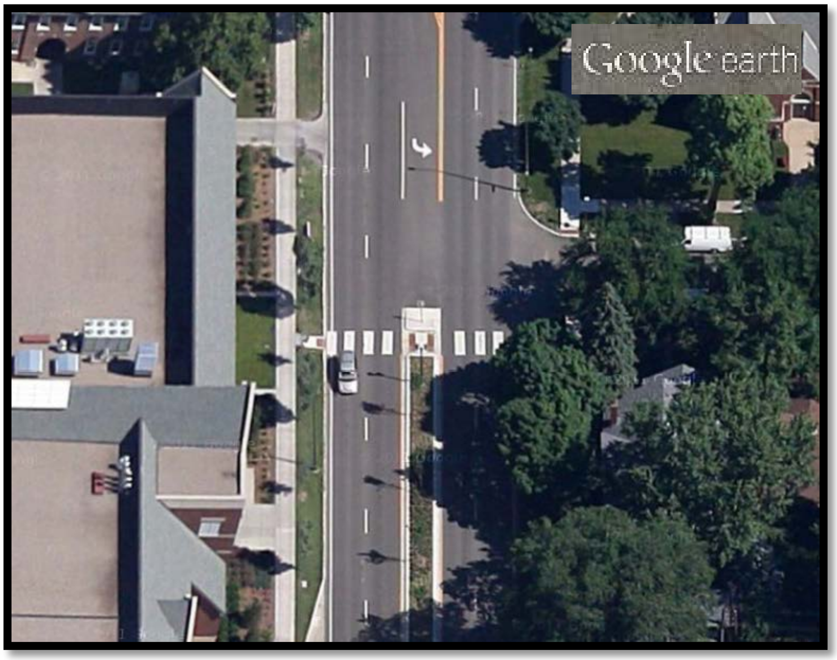

Figure 6.4 Potential Two-Stage Crossing [14]
St. Paul

Step 2: Determine Critical Headway

The critical headway is calculated in the same way critical headway is determined for the gap study. The critical headway calculation uses crosswalk length, average pedestrian walking speed, and pedestrian start-up and clearance times. [12]

$$t_c = \frac{L}{S_p} + t_s$$

Where:
t_c = critical headway for a single pedestrian (s),
S_p = average pedestrian walking speed (ft/s),
L = crosswalk length (ft), and
t_s = pedestrian start-up time and end clearance time (s).

The default for pedestrian walking speed is 3.5 ft/s unless field data on average speed can be collected at the actual crossing. Crossings that serve a significant volume of children or people with disabilities that may require a slower walk time while crossings with a significant volume of runners or teens may have faster walk times. The default for start-up and end clearance times is 3 sec unless field data can be collected.

Examples from real-world locations in Minnesota both from this study and other studies provide some collected pedestrian walking speeds at uncontrolled pedestrian crossings with a mix of no markings, marked and signed, flashing beacons, and Rectangular Rapid Flashing Beacons. It should be noted that although average walking speed is used in the HCM calculations, the 3.5 ft/s walking speed dictated in the MN MUTCD and other sources, is actually the 15th percentile speed and not the average. This ensures that 85% of pedestrians are able to cross faster than the walking speed accounted for or as in the case for a signalized crossing, ensure that 85% of pedestrians using a crossing are able to get across in the time allotted during a flashing don't walk.

Crossing	City, State	Existing Crossing Treatment	Average Collected Walking Speed (ft/s)	15th %ile Collected Walking Speed (ft/s)
CSAH 101 & Lake Dr E	Chanhassen, MN	Unmarked	5.6	5.3
Powers Blvd & Park Rd	Chanhassen, MN	Flashing Beacons	5.6	4.7
3rd St & Norm McGrew Plc	Minneapolis, MN	Overhead Flasher w/ Advance RRFB (one-way street)	4.4	3.7
CR 112 & Mill St	Long Lake, MN	Unmarked	too few pedestrians	too few pedestrians
CSAH 150 & S. School Crossing	Rogers, MN	Markings/Signs	4.2	3.8
CSAH 150 & N. School Crossing	Rogers, MN	Markings/Signs/ In-Street Sign	4.3	3.6
England Way & 17th Ave E	Shakopee, MN	Unmarked	4.7	4.2
Center Ave & TH 12	Montrose, MN	Flashing Beacons	4.5	2.2
TH 47 & CR 81	Saint Francis, MN	Overhead RRFB	7.0	5.2
Bank St & University Ave	Minneapolis, MN	Unmarked	5.7	4.6
Lafayette & 8th St	St. Paul, MN	Unmarked	4.2	3.7
Rice St at Sears (S. of Aurora Av)	St. Paul, MN	Markings/Signs	4.5	3.9
Rolling Acres Rd & Rolling Acres Ln	Victoria, MN	Markings/Signs	6.2	3.7
York Ave & Parklawn Ave	Edina, MN	Markings/Signs	4.8	4.1
	Average of All Sites		5.0	4.1

Table 6.1 Field Collected Walking Speeds

In most of the cases, whether the crossing was marked or unmarked, the average walking speed collected was faster than the 3.5 ft/s walking speed used as a default in the HCM calculations. Additionally, the 15th percentile walking speed collected for many of the sites was faster than 3.5 ft/s. While the above data provides a snapshot of some sites in Minnesota, additional research should be collected before drawing too many conclusions as the data appears to contradict other studies that have collected slower walking speeds. Overall, the above data indicates that collected data should always be used if available, as the defaults may give different results.

Additional data is needed when there is observed platooning. This includes crosswalk width, pedestrian flow rate, and vehicular flow rate. [12]

$$N_p = INT\left[\frac{8.0(N_c - 1)}{W_c}\right]$$

Where:
N_p = spatial distribution of pedestrians (ped),
N_c = total number of pedestrians in the crossing platoon,
W_c = crosswalk width (ft), and
8.0 = default clear effective width used by a single pedestrian to avoid interference when passing other pedestrians (ft).

In the absence of an actual painted crosswalk the default crosswalk width is eight feet or as wide as the curb ramps leading to the crossing location.

To compute spatial distribution, the number of pedestrians in the crossing platoon should be collected in the field or the platoon size can be estimated. [12]

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

Where:
N_c = total number of pedestrians in the crossing platoon (ped),
v_p = pedestrian flow rate (ped/s),
v = vehicular flow rate (veh/s), and
t_c = single pedestrian critical headway (s).

Group critical headway is:

$$t_{c,G} = t_c + 2(N_p - 1)$$

Where:
$t_{c,G}$ = group critical headway (s),
t_c = critical headway for a single pedestrian (s), and
N_p = spatial distribution of pedestrians (ped).

Step 3: Estimate Probability of a Delayed Crossing

The probability of a blocked lane due to a vehicle interfering with the pedestrian crossing results in a higher probability of the pedestrian being delayed. This essentially is used to determine the likelihood of the gaps in a given lane being of sufficient time to accommodate the critical headway assuming random arrivals of vehicles. This calculation is dependent on the number of lanes being crossed and the number of vehicles using the roadway in addition to the critical headway. [12]

The probability of a delayed crossing assumes random vehicle arrivals and consequentially may not provide adequate probabilities when calculating crossing delays across a street that is along a signalized corridor. [12]

$$P_b = 1 - e^{\frac{-t_{c,G} v}{L}}$$

$$P_d = 1 - (1 - P_b)^L$$

Where:
P_b = probability of a blocked lane,
P_d = probability of a delayed crossing,
L = number of through lanes crossed,
$t_{c,G}$ = group critical headway (s), and
v = vehicular flow rate (veh/s).

Step 4: Calculate Average Delay to Wait for Adequate Gap

The average pedestrian gap delay is calculated assuming that no motor vehicles yield and a pedestrian is forced to wait for an adequate gap. This uses the critical headway, vehicular flow rate, and probability of delayed crossing. [12]

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

Where:
d_g = average pedestrian gap delay (s),
$t_{c,G}$ = group critical headway (s), and
v = vehicular flow rate (veh/s).

The average delay for any pedestrian who is unable to cross immediately upon reaching the intersection is a function of the probability of a delayed crossing and the average pedestrian gap delay. [12]

$$d_{gd} = \frac{d_g}{P_d}$$

Where:
d_{gd} = average gap delay for pedestrians who incur nonzero delay (s),
d_g = average pedestrian gap delay (s), and
P_d = probability of a delayed crossing.

After Step 4, if there are no crossing treatments, skip to Step 6.

Step 5: Estimate Delay Reduction due to Yielding Vehicles

Pedestrian crossing treatments can affect the rate in which a motorist yields to a pedestrian. The average pedestrian delay is calculated using average headway for each through lane, probability of yielding, and average gap delay.

This step can be used to determine the effect of a potential crossing treatment to vehicle yielding and consequentially average pedestrian delay.

Determine if there is a crossing treatment used that could provide vehicle yielding. Crossing treatments with researched yield rates are included in Table X. This then provides possible reduction in actual delay. [12]

$$d_p = \sum_{i=1}^{n} h(i - 0.5)\, P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right) d_{gd}$$

and

$$n = INT\left(\frac{d_{gd}}{h}\right)$$

Where:
d_p = average pedestrian delay (s),
i = crossing event ($i = 1\ to\ n$),
h = average headway for each through lane,
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i,
INT = integer, and
n = average number of crossing events before an adequate gap is available, must be 1 or more.

The probabilities $P(Y_i)$ that motorists will yield for different lane crossings are: [12]

One-Lane Crossing

$$P(Y_i) = P_d M_y \left(1 - M_y\right)^{i-1}$$

Two-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P\left(Y_j\right)\right]\left[\frac{\left(2P_b(1 - P_b)M_y\right) + \left({P_b}^2 {M_y}^2\right)}{P_d}\right]$$

Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P\left(Y_j\right)\right]\left[\frac{{P_b}^3 {M_y}^3 + 3{P_b}^2(1 - P_b){M_y}^2 + 3P_b(1 - P_b)^2 M_y}{P_d}\right]$$

Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] \text{x}$$

$$\left[\frac{{P_b}^4{M_y}^4 + 4{P_b}^3(1-P_b){M_y}^3 + 6{P_b}^2(1-P_b)^2{M_y}^2 + 4P_b(1-{P_b}^3)M_y}{P_d}\right]$$

Where:
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i,
i = crossing event ($i = 1\ to\ n$),
P_d = probability of a delayed crossing,
P_b = probability of a blocked lane,
M_y = motorist yield rate (decimal),
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j,
j = crossing event ($j = 0\ to\ i-1$), and
$P(Y_0)$ = 0.

Potential crossing treatments and the motorist yield rates shown on the next page.

Crossing Treatment	Staged Pedestrian Motorist Yield Rate	Unstaged Pedestrian Motorist Yield Rate
Crosswalk Markings and Signs Only (1)	7%	7%
Median Refuge Islands (1)	34%	29%
Pedestal Mounted Flashing Beacon (2-Lane, 35 mph) (3)	N/A	57%
Overhead Flashing Beacon (push-button activation) (1)	47%	49%
Overhead Flashing Beacon (passive activation) (1)	31%	67%
Pedestrian Crossing Flags (1)	65%	74%
School Crossing Guards (5)	N/A	86%
In-street Crossing Signs (25-30 mph) (1)	87%	90%
Warning Sign with Edge Mounted LEDs (6)	N/A	28%
In-road warning lights (1)	N/A	66%
High-visibility Signs and Markings (35 mph) (1)	17%	20%
High-visibility Signs and Markings (25 mph) (1)	61%	91%
Rectangular Rapid-Flash Beacon (RRFB) (2)(4)	84%	81%
School Crossing Guards with RRFB (5)	N/A	91%
Pedestrian Hybrid Beacon (HAWK) (1)	97%	99%
	N/A: No Research Found on Effect to Yielding Rate	

Crossing treatment motorist yield rate sources provided on the next page.

Table 6.2 Crossing Treatment Yield Rates

Crossing treatment yield rate sources:

(1) Fitzpatrick, K., S.M. Turner, M. Brewer, P.J. Carlson, B. Ullman, N.D. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.

(2) Lewis, R., J.R. Ross, D.S. Serpico : Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.

(3) Bolton & Menk Field Data Collection

(4) Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.

(5) Brewer, Marcus A., Kay Fitzpatrick. Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

(6) Kipp, Wendy M.E., Jennifer M. V. Fitch. Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report. Vermont Agency of Transportation, Report 2011-3, Montpelier, VT, February 2011. (Rate Normalized to High Visibility Markings and Signs at 35 mph)

Step 6: Calculate Average Pedestrian Delay and Determine LOS

Sum the delay for each stage of a two stage crossing or use the delay from a one-stage crossing and use the following table to determine the level of service (LOS) for the crossing movement. [12]

LOS	Control Delay (sec/pedestrian)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconveniencing
D	20-30	Delay noticeable and irritating, increased likelihood of risk taking
E	30-45	Delay approaches tolerance level, risk-taking behavior likely
F	>45	Delay exceeds tolerance level, high likelihood of pedestrian risk-taking

Table 6.3 Pedestrian Mode Level of Service

LOS F indicates that there are not enough gaps of suitable size to allow pedestrians to cross through traffic on the major street safely. LOS F may result in pedestrians selecting smaller than usual gaps, indicating a safety concern that warrants further study.

Evaluation Worksheets are provided on the following pages.

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations
Intersection and Mid-Block Crossings

Introduction:

The Worksheets provide a procedure for evaluating the Level of Service (LOS) at uncontrolled pedestrian crossings according to the methodology presented in Chapter 19 of the 2010 Highway Capacity Manual. Uncontrolled pedestrian crossings include: marked crossings at mid-block locations; marked crossings at intersections; and unmarked crossings at intersections, that are not controlled by a traffic control device such as signals and stop or yield signs.

Use of these Worksheets in Microsoft Excel results in an automated procedure. While this automated procedure has been checked for accuracy using multiple examples, no warranty is made by the developers as to the accuracy, completeness, or reliability of the equations and results. No responsibility is assumed for incorrect results or damages resulting from the use of these worksheets.

This process is not for use at signalized crossings and has not been verified to be accurate for unsignalized pedestrian crossings within a signalized corridor.

The equations and methodology presented through this process is contained within the 2010 Highway Capacity Manual (HCM). Any questions on the approach, assumptions, and limitations of the procedure or for verification of equations are directed to the 2010 HCM.

This material was developed by Bolton & Menk, Inc. in coordination with the Local Road Research Board (LRRB) for the use by practicioners. These Worksheets are made without charge and under no circumstances shall be sold by third parties for profit.

Submitted for Approval: May 12, 2014
Updated June 6, 2014

Developed by Bolton & Menk, Inc. for the
Local Road Research Board

Introduction

Page 1 of 5

HCM Evaluation Worksheet

Figure 6.5 Highway Capacity Manual Evaluation Worksheet (Page 1)

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	______________	Date:	______________
City, State:	______________	Scenario:	______________
Reviewer(s):	______________	Agency:	______________
Project Number:	______________	ID #:	______________

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: ______________

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing 2: ______________ (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay		sec/ped
LOS		

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Inputs and Results

Page 2 of 5

HCM Evaluation Worksheet

Figure 6.6 Highway Capacity Manual Evaluation Worksheet (Page 2)

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location: ______________________ Date: ______________________

City, State: ______________________ Scenario: ______________________

Reviewer(s): ______________________ Agency: ______________________

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing? ☐ Yes ☐ No

If yes, does the median refuge meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No

If yes, do pedestrians treat this as a two-stage crossing location? ☐ Yes ☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)

crossing 1		crossing 2	
L =	t_s =	L =	t_s =
S_p =	t_c =	S_p =	t_c =

S_p = 3.5 ft/s
t_s = 3 sec

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1		crossing 2	
v_p =	t_c =	v_p =	t_c =
v =	N_c =	v =	N_c =

2. compute spatial distribution:

$$N_p = INT\left[\frac{8.0(N_c - 1)}{W_c}\right]$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)

crossing 1		crossing 2	
N_c =		N_c =	
W_c =	N_p =	W_c =	N_p =

clear width, if other than 8: ______ ft.

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1		crossing 2	
N_p =		N_p =	
t_c =	$t_{c,G}$ =	t_c =	$t_{c,G}$ =

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{\frac{-t_{c,G} v}{L}}$$

$$P_d = 1 - (1 - P_b)^L$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of through lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1		crossing 2	
$t_{c,G}$ =		$t_{c,G}$ =	
v =	P_b =	v =	P_b =
N =	P_d =	N =	P_d =

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HCM Evaluation Worksheet

Figure 6.7 Highway Capacity Manual Evaluation Worksheet (Page 3)

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{vt_{c,G}} - vt_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1		crossing 2	
$t_{c,G}$ =		$t_{c,G}$ =	
v =	d_g =	v =	d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1		crossing 2	
d_g =		d_g =	
P_d =	d_{gd} =	P_d =	d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all intersections and at all marked crossings, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i-0.5)\,P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right) d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1		crossing 2	
h =	n =	h =	n =
	d_p =		d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b{}^2 M_y{}^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{P_b{}^3 M_y{}^3 + 3P_b{}^2(1-P_b)M_y{}^2 + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \Sigma_{j=0}^{i-1} P(Y_j)\right] \times \left[\frac{P_b{}^4 M_y{}^4 + 4P_b{}^3(1-P_b)M_y{}^3 + 6P_b{}^2(1-P_b)^2 M_y{}^2 + 4P_b(1-P_b{}^3)M_y}{P_d}\right]$$

Summary	
Average	
LOS	

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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HCM Evaluation Worksheet

Figure 6.8 Highway Capacity Manual Evaluation Worksheet (Page 4)

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Motorist Yield Rate = M_y

Determine if there is a crossing treatment used that could provide vehicle yielding. This then provides a possible reduction in delay.

Crossing Treatment	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate
Crosswalk Markings and Signs Only [1]	7%	7%
Median Refuge Islands [1]	34%	29%
Pedestal Mounted Flashing Beacon (2-Lane, 35 mph) [3]	N/A	57%
Overhead Flashing Beacon (push-button activation) [1]	47%	49%
Overhead Flashing Beacon (passive activation) [1]	31%	67%
Pedestrian Crossing Flags [1]	65%	74%
School Crossing Guards [5]	N/A	86%
In-street Crossing Signs (25-30 mph) [1]	87%	90%
Warning Sign with Edge Mounted LEDs [6]	N/A	28%
In-road warning lights [1]	N/A	66%
High-visibility Signs and Markings (35 mph) [1]	17%	20%
High-visibility Signs and Markings (25 mph) [1]	61%	91%
Rectangular Rapid-Flash Beacon (RRFB) [2][4]	84%	81%
School Crossing Guards with RRFB [5]	N/A	91%
Pedestrian Hybrid Beacon (HAWK) [1]	97%	99%
	N/A: No Research Found on Effect to Yielding Rate	

Sources: (1) Fitzpatrick, K., S.M. Turner, M. Brewer, P.J. Carlson, B. Ullman, N.D. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.

(2) Lewis, R., J.R. Ross, D.S. Serpico : Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.

(3) Bolton & Menk Field Data Collection

(4) Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.

(5) Brewer, Marcus A., Kay Fitzpatrick. Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

(6) Kipp, Wendy M.E., Jennifer M. V. Fitch. Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report. Vermont Agency of Transportation, Report 2011-3, Montpelier, VT, February 2011. (Rate Normalized to High Visibility Markings and Signs at 35 mph)

Developed by Bolton & Menk, Inc. for the LRRB. Yield Rates (M_y) Page 5 of 5

HCM Evaluation Worksheet

Figure 6.9 Highway Capacity Manual Evaluation Worksheet (Page 5)

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Chapter 7

Evaluation Procedure

The location details, evaluation, decisions, and design process should be thoroughly documented. This includes any stakeholder involvement and public comments. The jurisdictional authority has the final decision on the control and design of pedestrian crossing features on their roadways.

Using the information provided in Chapters 2 through 6, a crossing evaluation procedure has been developed to take into consideration safety and operations. The procedure is based on previous research and evaluation methodologies.

The evaluation methodology guidance is shown in the flowchart, Figure 7.1.

STEP 1

Step 1. Field Data Review

The Field Data Review should consider the elements defined under Chapter 4 of this report.

Information to be collected should include

- Geometrics
    - Crossing Length
        - pedestrian exposure is reduced on shorter crossings
    - Median Width
        - if used by pedestrians the median should be sufficient in size to handle the pedestrians using it
    - Curb Ramps
        - curb ramps are required for all pedestrian crossing locations
    - Americans with Disabilities Act (ADA) Requirements
        - ADA requirements for pedestrian crossings including grades, tactile surfaces/truncated domes, and landing areas.
    - Roadway Speed
        - for a pedestrian/vehicle crash slower speeds have been shown to reduce the possibility of a fatal crash
    - Roadway Curvature
        - vertical and horizontal curvature can impact sight lines
    - Sight Distance
        - Stopping Sight Distance
            - must be provided at pedestrian crossings
        - Pedestrian Sight Distance
            - should be provided at unmarked and unsigned crossings
- Traffic and Pedestrian Data
    - Vehicle Traffic Volume
    - Pedestrian Traffic Volume

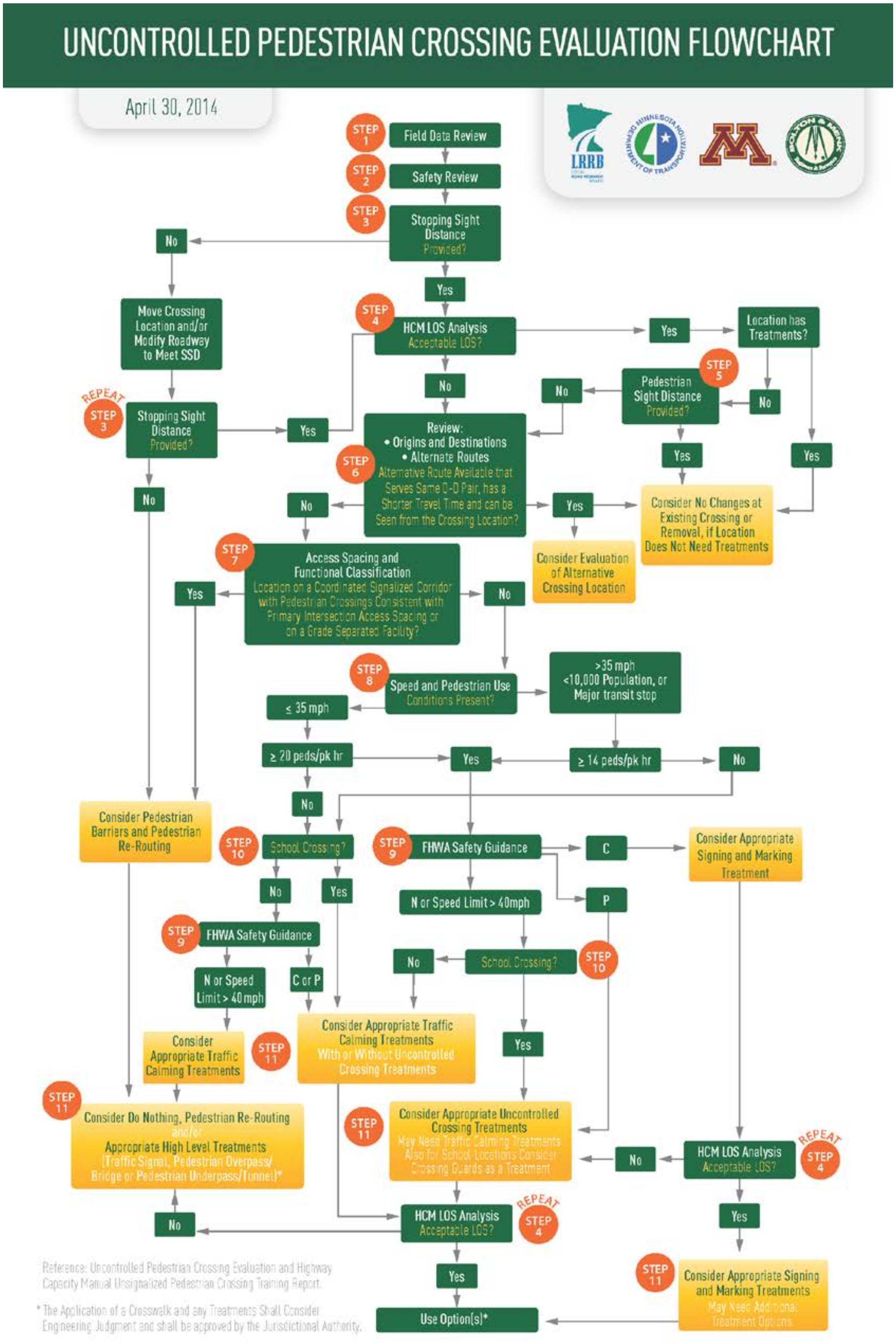

Figure 7.1 Uncontrolled Pedestrian Crossing Evaluation Flowchart

- Additional Site Characteristics
  - Lighting
    - should be provided at marked crossings used at night and provide positive contrast
  - Crosswalk Pavement Markings
    - must follow the designs as stated in the Manual on Uniform Traffic Control Devices
  - Signing
    - must follow the design and placement as stated in the Manual on Uniform Traffic Control Devices
  - Enhancements
    - enhancements installed at the crossing location may or may not be appropriate and provide effective yielding
  - Distance to Adjacent Pedestrian Crossing Facilities
    - an adjacent crossing location may provide a shorter travel time, less delay, a safer crossing environment, and/or a more direct route between origins and destinations
  - Distance to Adjacent Intersections with All-Way Stop, Signal, or Roundabout Control
    - an adjacent controlled crossing location may provide a shorter travel time
  - Origins and Destinations
    - all marked crossings should serve a needed origin-destination connection
    - Typical origins and destinations of importance include:
      - Bus stops
      - High density residential
      - Hospitals and medical centers
      - Retirement communities
      - Schools, colleges, and universities
      - Parks
      - Recreational and community centers
      - Theatres and museums
      - Trails

STEP 2

Step 2. Safety Review

The safety review includes evaluating the crash records for the crossing location. Pedestrian crashes may necessitate a more in-depth look into the issues and concerns at a crossing location. The field review can assist with determining potential issues. This includes an inspection of potential hazards and may include a visual view of operations.

Rear-end crashes at a location may indicate that motorists are stopping for pedestrians but may also indicate that there is inadequate stopping sight distance.

Other types of crashes should be reviewed to determine if the conflicts are impacting the crossing safety and may indicate other intersection concerns.

Step 3. Stopping Sight Distance

Every pedestrian crossing location should have adequate Stopping Sight Distance (SSD). If adequate SSD cannot be provided at a potential crossing location, the location may not be suitable for a pedestrian crossing. Adequate SSD ensures that most motorists under normal conditions will be able to stop for a pedestrian that has entered onto the roadway. If SSD cannot be met, pedestrian barriers and pedestrian routing to an alternative location should be considered. Pedestrian barriers can include fencing, concrete barriers, and/or bushes. The pedestrian barrier should be continuous between acceptable crossing locations to guide pedestrians to the locations to be used. Any breaks in the barrier, such as for a driveway or street access, will likely result in the pedestrian crossing at that location. Pedestrian routing may include wayfinding signage to guide pedestrians to the acceptable alternative crossing locations.

Step 4. Level of Service

Determine the Level of Service (LOS) of the current crossing condition following the procedure as outlined in the 2010 Highway Capacity Manual and Chapter 6 of this report.

LOS is generally deemed acceptable at A to D and unacceptable at E or F. Local agency direction on acceptable service levels should be verified. If the Level of Service is acceptable and the location already has treatments such as signing and/or striping, consider no changes at the existing crossing. If the crossing location has acceptable service levels without any treatments, consider removal of the treatments.

If LOS is unacceptable, skip to Step 6. If this is completed after Step 11, consider applying appropriate treatment option(s) if LOS is acceptable.

Step 5. Pedestrian Sight Distance

If adequate service levels are provided, Pedestrian Sight Distance (PedSD) should be checked if the crossing does not have any treatments (i.e. is unmarked and unsigned). If adequate PedSD is provided, consider no changes at the existing crossing.

Step 6. Review Origins and Destinations

The potential origins and destinations in the area should be reviewed for the most likely path to determine how it lines up with the crossing being analyzed. The most important thing to remember is that pedestrians will take the shortest route if at all possible. Understanding this is of essential importance in understanding why a route is being used, especially when there are alternatives available that may actually be safer and provide less delay. In some cases existing crossings may not actually be placed where pedestrians are using them if the understanding of origins and destinations is incorrect.

Studies have shown that many pedestrians will take the fastest route and the most direct route irrespective of the safety potential of the crossing location. [18] The percentage of pedestrians using the most direct route and fastest route are higher for younger people than older. Additionally if traffic is sparse, the percentage of pedestrians crossing at a given location, irrespective of the crossing treatments, is 40 to 60% and is generally equal between younger and older people. [19]

Check to see if an alternative route is available that can serve the same origin-destination pair (same movements) effectively while providing less delay. This includes the time to traverse to the alternative crossing, cross, and complete the movement to the destination. Average wait time at signals should be added into the equation if the crossing requires traversing a traffic signal.

Additionally, the alternative crossing route location should be visually seen from the location being studied. If the crossing cannot be seen there is no way for the pedestrian to know if it is available, unless there is route signage. Even with route signage, the potential trip length may not be known to a pedestrian if the crossing cannot be seen. This can affect the potential use of the alternative crossing location.

If the primary origin-destination movements can be accomplished effectively at another crossing without much backtracking, has a shorter travel time and can be seen from the location being studied, there should be consideration for no change at the existing crossing. The alternative crossing location should be evaluated separately to determine the needs at that crossing location.

STEP 7

Step 7. Access Spacing and Functional Classification

The functional classification of the roadway and the current access control of the roadway being crossed should be considered. Marked uncontrolled pedestrian crossings should only be implemented on signalized roadway corridors if the spacing between the signalized intersections does not adequately serve the pedestrian traffic in the community. The spacing of pedestrian crossing facilities should at least follow the access spacing guidelines for signals and primary intersections on the corridor of interest. Primary access intersections are intersections that will remain full access over time while secondary access intersections may provide full or limited access over time.

Due to the limited access along grade-separated roadway facilities, marked and unmarked pedestrian crossings are limited to interchanges, tunnels, and bridges. The high speed of the facilities along with the driver expectations for conflicts makes any at-grade crossing a safety concern. If the crossing location is on a coordinated signalized corridor or a grade-separated facility, pedestrian barriers and pedestrian routing to an alternative location should be considered. Pedestrian barriers can include fencing, concrete barriers, and/or bushes. The pedestrian barrier should be continuous between acceptable crossing locations to guide pedestrians to the locations to be used. Any breaks in the barrier, such as for a driveway or street access, will likely result in the pedestrian crossing at that location. Pedestrian routing may include wayfinding signage to guide pedestrians to the acceptable alternative crossing locations.

Step 8. Speed and Pedestrian Use

Consistent with previous research and evaluation methods, the conditions present at the crossing location should be reviewed and the need for the crossing should consider pedestrian traffic volume using the crossing. It is important that the pedestrian use be collected at multiple times of day to get an accurate picture of the pedestrian traffic need. The highest hour pedestrian need may not coincide with the highest hour traffic volume crossing the location. In such circumstances, the Level of Service should be evaluated for the highest pedestrian volume hour and the highest vehicle volume hour separately.

If the crossing location is on a roadway with speeds greater than 35 miles per hour (mph), is in a community of less than 10,000 people, or provides a connection to a major transit stop, there should be a minimum of 14 pedestrians using the crossing during one hour of the day.

If the crossing location is on a roadway with speed 35 mph or less there should be a minimum of 20 pedestrians using the crossing during one hour of the day.

The above pedestrian volumes thresholds can be reduced by 0.33 if more than 50% of the pedestrian traffic using the crossing is elderly or children.

If the thresholds cannot be met, skip to Step 10.

Step 9. FHWA Safety Guidance

The Federal Highway Administration (FHWA) guidance in the Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations and as shown in Chapter 5 should be determined based on the traffic volume, speed, and roadway type. The study indicates the types of treatments recommended for installing marked crosswalks at uncontrolled locations.

Research indicates that there is a statistically significant difference in the safety between a marked and unmarked crossing when traffic volume is over 15,000 or over 12,000 without a median under most speeds and provides the basis for the guidance in the table.

It is important to recognize that the research indicates where pedestrian crossing markings alone may or may not be sufficient. The research does not indicate where pedestrian crossings with alternative treatments should or should not be located. In all cases, an engineering study should be completed to determine whether a location is suitable or not, and if additional pedestrian crossing treatments are justified.

The FHWA recommendations for installing marked crosswalks and other treatments is included in Table 7.1.

Table Definitions

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.
It is important to recognize that the research indicates where pedestrian crossing markings alone may or may not be sufficient. The research does not indicate where pedestrian crossings with alternative treatments should or should not be located. In all cases, an engineering study should be completed to determine whether a location is suitable or not, and if additional pedestrian crossing treatments are justified. [11]

Table 11. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000-15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.

*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = **Candidate sites for marked crosswalks** . Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more indepth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = **Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements.** These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = **Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone.** Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

In some situations (e.g., low-speed, two-lane streets in downtown areas), installing a marked crosswalk may help consolidate multiple crossing points. Engineering judgment should be used to install crosswalks at preferred crossing locations (e.g., at a crossing location at a streetlight as opposed to an unlit crossing point nearby). While overuse of marked crossings at uncontrolled locations should be avoided, higher priority should be placed on providing crosswalk markings where pedestrian volume exceeds about 20 per peak hour (or 15 or more elderly pedestrians and/or children per peak hour).

Marked crosswalks and other pedestrian facilities (or lack of facilities) should be routinely monitored to determine what improvements are needed.

[11]

Table 7.1 Recommendations for Installing Marked Crosswalks at Uncontrolled Location

Step 10. School Crossings

The safety of children to get to and from school is of special consideration that may require the implementation of a crosswalk at locations that might otherwise not be considered. A school crossing location will traditionally have significant use by children that occurs consistent with school start and dismissal times, making the crossing use noticeable to motorists. Consider appropriate treatment options including crossing guards. At higher traffic speed crossings, this includes appropriate traffic calming treatments in addition to other treatments.

If this step is completed directly after Step 8, and the location is not a school crossing location, go to Step 9.

Step 11. Consider Appropriate Treatment Options

Appropriate treatment options should be considered for crossing locations as based on the evaluation flowchart. In many cases, the most appropriate option is to keep the location unmarked and unsigned (i.e. “Do Nothing”,) as any treatment may increase the crash potential at the location.

The treatment options have been organized into four separate categories as shown in Table 7.2 to 7.5 depending on their primary function in serving pedestrian crossings.

- Signing and Marking Treatments
- Uncontrolled Crossing Treatments
- Traffic Calming Treatments
- High Level Treatments

Some of the options have not been shown to have any noticeable impact to motorist yielding and service levels, but are provided as examples that have been implemented by some agencies. Many of the traffic calming treatments may not directly impact motorist yielding but do result in shorter crossing distances and a potential for lower traffic speeds. For ADA compliant versions of the treatment summary tables, please see Appendix A.

In all cases, when speed limits are over 40 mph and/or the FHWA guidance indicates an N designation, it may be appropriate to consider traffic calming treatments, no matter the other treatments recommended.

Signing and Marking Treatments

Signing and Marking Treatments (Table 7.2) are generally low cost and provide little to no benefit in terms of operational impacts. The most significant impact is for High Visibility Markings. The treatments can be appropriate by themselves on low volume and low speed roadways unless accompanied by other types of treatments.

Figure 7.2 Standard Crosswalk Markings

Figure 7.3 Advance Pedestrian Crossing Warning Sign

Figure 7.4 In-Street Crossing Sign

Figure 7.5 Pedestrian Crossing Warning Sign with Down Arrow

Figure 7.6 High Visibility Continental Crosswalk Markings

Signing and Marking Treatments
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate		Cost
				Staged Pedestrian	Unstaged Pedestrian	
Crosswalk Markings Only	Inexpensive Helps define a crossing location Indicates to drivers that a crossing location is present	Very little effect at night Speeds increase over time Not been shown to reduce crashes	Not usually recommended alone Low volume and low speed roadways Where justified	NR	NR	\$500 to \$2,000
Warning Signs	Inexpensive Helps define a crossing location Warning to drivers that a crossing location is present	Tend to be ignored unless pedestrians use the crossing consistently Proven to be ineffective at reducing crashes at uncontrolled intersections	Where unexpected entries into the roadway by pedestrians may occur Either at or before the crossing location Either with or without a marked crosswalk	NR	NR	\$300 to \$1,200
Overhead Warning Signs	Visual distance increased Warning to drivers that a crossing location is present Signs easier to see when have multiple lanes of approach	Requires overhead structure Tend to be ignored unless pedestrians use the crossing consistently	Multi-lane roadways Midblock crossing locations Usually coupled with other measures such as RRFBs or beacons	NR	NR	\$60,000 to \$75,000
Colored Concrete/Brick Pavers	May decrease vehicle speed	Can be expensive Not been shown to reduce crashes Speeds increase over time	Downtown/Urban conditions Traffic signal locations In conjunction with pavement markings	NR	NR	\$10,000 to \$75,000
Crosswalk Markings and Signs	Inexpensive Warning to drivers that a crossing location is present May decrease vehicle speed	Very little effect at night Not been shown to reduce crashes Speeds increase over time	Where justified	7%	7%	\$800 to \$3,200
In-Street Crossing Signs (25 to 30 mph)	Inexpensive Additional Warning to drivers that a crossing location is present	May make snow removal more difficult Need consistent maintenance and replacement due to vehicle hits	Downtown/Urban conditions Supplement warning signs at high pedestrian volume locations In conjunction with pavement markings	87%	90%	\$500 to \$1,000
High Visibility Crosswalk Markings	May decrease vehicle speed	Not been shown to reduce crashes Speeds increase over time	Where justified Urban conditions	61% (25mph) 17% (35 mph)	91% (25 mph) 20% (35 mph)	\$5,000 to \$50,000

NR = No Research Found on Effect to Yielding Rate

Table 7.2 Signing and Marking Treatments

Uncontrolled Crossing Treatments

Uncontrolled Crossing Treatments generally provide some level of increased yielding rate. They are generally applied to locations with marked crosswalks to provide an extra level of operational and safety benefit due to higher volume and speeds. Many of the treatments are pedestrian activated.

Figure 7.7 Center Median with Refuge Island

Figure 7.8 School Crossing Guard

Figure 7.9 Pedestal Mounted Flashing Signal Beacons

Figure 7.10 Overhead Flashing Signal Beacons

Figure 7.11 Rapid Rectangular Flashing Beacons (RRFB)

Figure 7.12 In-Road Warning Lights with Edge Lit Warning Sign

Uncontrolled Crossing Treatments (in conjunction with markings and signs)
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate		Cost
				Staged Pedestrian	Unstaged Pedestrian	
Center Median with Refuge Island	Decreases pedestrian crossing distance Provides higher pedestrian visibility Reduces vehicle Speeds approaching the island Reduces conflicts Increases usable gaps Reduces pedestrian exposure time	May make snow removal more difficult May be a hazard for motorists Small islands not recommended on high speed (>40 mph) roadways	Wide two-lane roads and multi-lane roads with sufficient right-of-way	34%	29%	Variable depending on length
School Crossing Guards	Inexpensive Provides higher pedestrian visibility to drivers Highlights when a pedestrian crossing is being used	May require trained staff or local law enforcement, especially on high speed and high volume roadways	At school locations	NR	86%	Variable
Pedestrian Crossing Flags	Inexpensive Provides higher pedestrian visibility to drivers assuming the flag is held In a noticeable location	No effect at night Requires pedestrian to actively use a flag Can be easily removed/stolen Shorter crossings are preferred	Downtown/Urban locations High pedestrian volume locations Across low speed (<45 mph) roadways	65%	74%	<$500
Warning Sign with Edge Mounted LEDs	Highlights a crossing both at night and during the day	Requires pedestrian activation Minimal to no effect on speed	In conjunction with In-Road Warning Lights Downtown/Urban conditions	NR	28%	$3,000 to $8,000
In-Road Warning Lights	Highlights a crossing both at night and during the day Provides higher driver awareness when a pedestrian is present	Snow plows can cause maintenance issues No effect when road surface is covered In snow Requires pedestrian activation	Downtown/Urban conditions	NR	66%	$20,000 to $40,000
Pedestal Mounted Pedestrian Flashing Signal Beacons	Provides higher driver awareness when a pedestrian is present	Requires pedestrian activation Not advisable on multi-lane streets Not been shown to reduce crashes	Low speed school crossings Two lane roadways Midblock crossing locations	NR	57% (2-Lane, 35 mph)	$12,000 to $18,000
Pedestrian Overhead Flashing Signal Beacons	Provides higher driver awareness when a pedestrian is present	Requires pedestrian activation	Multi-lane roadways Midblock crossing locations Lower speed roadways	active 47% passive 31%	active 49% passive 67%	$75,000 to $150,000
Rectangular Rapid Flash Beacons (RRFBs)	Provides higher driver awareness when a pedestrian is present Increases yielding percentage increase In usable gaps Reduces the probability of pedestrian risk taking Can be configured to be seen from 360 degrees	Requires pedestrian activation	Supplement existing pedestrian crossing warning signs School Crossings Midblock crossing locations Low and high speed roadways	84%	81%	$12,000 to $18,000

NR = No Research Found on Effect to Yielding Rate

Table 7.3 Uncontrolled Crossing Treatments

Traffic Calming Treatments

Traffic Calming Treatments are generally applied to locations that are experiencing high traffic speeds. Traffic speeds should be lowered to enable any type of at-grade crossing. They can also be used to shorten crossing distances and improve pedestrian visibility. The shortened crossing distances reduce the total time of exposure to conflicting traffic. This reduced exposure results in safer crossing environments. These treatments may be completed in conjunction with Uncontrolled Crossing Treatments and/or other treatments if determined to be necessary.

Figure 7.13 Center Median with Refuge Island

Figure 7.14 Crossing Location Lighting

Figure 7.15 Pavement Striping/Road Diet

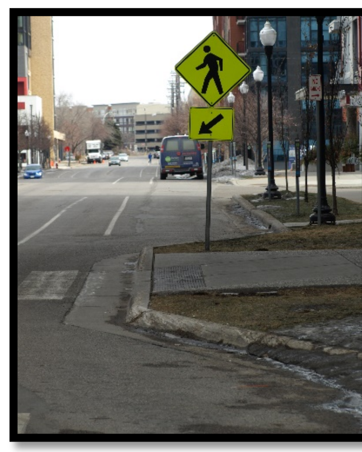

Figure 7.16 Curb Bump-Out

Figure 7.17 Channelized Turn Lane with Raised Crossing

Traffic Calming Treatments

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate: Staged Pedestrian	Motorist Yield Rate: Unstaged Pedestrian	Cost
Center Median with Refuge Island	Decreases pedestrian crossing distance Provides higher pedestrian visibility Reduces vehicle speeds approaching the island Reduces conflicts Increases usable gaps Reduces pedestrian exposure time	May make snow removal more difficult May be a hazard for motorists Small islands not recommended on high speed (>40 mph) roadways	Wide two-lane roads and multi-lane roads with sufficient right-of-way	34%	29%	Variable depending on length
Raised Crossings	Provides higher pedestrian visibility to vehicles Can reduce vehicle Speeds	May make snow removal more difficult May reduce emergency vehicle response times Only appropriate In Low speed/Urban environments	Low speed/Urban environments	NR	NR	$5,000 to $25,000
Lighting	Can be inexpensive Highlights a crossing at night	No effect during daylight	Targeted crossing locations not located on a street with continuous roadway lighting	NR	NR	$1,000 to $40,000
Pavement Striping (Road Diet)	Can be inexpensive May decrease vehicle speed May decrease illegal right side passing Can be an interim solution	Does not provide a physical barrier between modes Pedestrian crossing distance same as existing	Four-lane undivided roadways Locations with very long crossings	NR	NR	Variable depending on length
Curb Bump-Outs/Extensions	Can be inexpensive Reduces pedestrian crossing distance Provides higher pedestrian visibility to vehicles Reduces speed for turning vehicles Decrease in illegal right side passing	May make snow removal more difficult Proximity of curb to through traffic may be a safety concern	Downtown/Urban conditions	NR	NR	$5,000 to $15,000 per crossing
Channelized Turn Lanes (Corner Islands) (Not Usually Recommended as a Pedestrian Crossing Treatment)	Decrease pedestrian crossing distance Provides higher pedestrian visibility Decrease in illegal right side passing	May require new pavement Can be more challenging for visually impaired pedestrians Right turning drivers often fail to yield to pedestrians Can increase right turn vehicle speeds May make snow removal more difficult Vehicle crashes may increase	Intersections with wide approaches Intersections with right turn lanes and sufficient corner right-of-way Intersections with operational improvement needs	NR	NR	$50,000 to $100,000 per intersection

NR = No Research Found on Effect to Yielding Rate

Table 7.4 Traffic Calming Treatments

High Level Treatments

High Level Treatments are generally high cost and are generally implemented on high volume and high speed roadways. They are much more difficult to implement unless they are justified based on traffic and pedestrian volume.

Figure 7.18 Pedestrian Hybrid Beacon

Figure 7.19 Pedestrian Traffic Signal

Figure 7.20 Underpass

Figure 7.21 Overpass

High Level Treatments
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate: Staged Pedestrian	Motorist Yield Rate: Unstaged Pedestrian	Cost
Pedestrian Hybrid Beacon	Provides higher driver awareness when a pedestrian is present Has been shown to decrease pedestrian crashes	Potential increase in vehicle crashes Can have spotty compliance rates due to a lack of driver understanding	Justified locations Midblock crossing locations	97%	99%	\$150,000 to \$300,000
Traffic Signal	Provides higher driver awareness when a pedestrian is present Easily understandable	May increase crashes due to the driver expectation of a green signal indication	High pedestrian volume crossings Justified locations, meets signal warrants	NA	NA	\$100,000 to \$300,000
Underpass Grade Separation	Removes pedestrian/vehicle conflicts	Potential of the crossing not being used Very location specific Very expensive Drainage within an underpass can be problematic Underpass would require lighting	Location with compatible grades High pedestrian volume crossings High volume roadways High speed roadways	NA	NA	\$800,000+
Overpass Grade Separation	Removes pedestrian/vehicle conflicts	Potential of the crossing not being used Very location specific Very expensive Snow removal on overpass may be difficult	Location with compatible grades High pedestrian volume crossings High volume roadways High speed roadways	NA	NA	\$1,200,000+

NA = Not Applicable or No Research Found on Effect to Yielding Rates

Table 7.5 High Level Treatments

The specific instance in which to use each treatment option is up to engineering judgment, but recommended locations are provided as a starting basis. Additional research into which treatments to use in which situations should be studied further and would provide valuable insight to be used by agencies for consistent application of treatments. For additional information on treatment options, please see:

- Minnesota Department of Transportation, "Minnesota's Best Practices for Pedestrian/Bicycle Safety," MnDOT Office of Traffic, Safety and Technology, Roseville, MN, September 2013.
- D. A. Noyce, "Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments," Minnesota Department of Transportation, St.Paul, MN, September 2013.

Repeat Step 4. Evaluate LOS for Treatment Option(s)

Step 4 should be repeated after deciding on a potential treatment option. Determine the Level of Service (LOS) of the crossing condition with the potential treatment options following the procedure as outlined in the 2010 Highway Capacity Manual and Chapter 6 of this report. An acceptable service level should be determined by the Agency. If acceptable service levels cannot be met:

- Do Nothing (consider leaving the crossing unmarked and unsigned,)
- Consider a different treatment option,
- Consider pedestrian routing to another location, and/or
- Consider High Level Treatments, if justified.

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Chapter 8

Examples

Using the information provided in Chapters 2 through 6, some examples from Minnesota are provided. The names of cities, streets, and other location specific information has been removed as these examples and results have not been approved by the jurisdictional authority.

Examples 1 through 4 include the full analysis, equations, and procedure while examples 5 through 10 include a brief synopsis of the procedure but all analysis is completed in the attached worksheets.

Example 1: Two-Lane Rural Highway Trail Crossing

<u>Site Review</u>
Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location connects a Regional Trail. The trail crossing extends across the two-lane highway. The crossing has no medians, has pavement markings and pedestrian crossing warning signs.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 1: Two-Lane Rural Highway	Date:	
City, State:	Any City, Minnesota	Scenario:	Trail Crossing
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.	Crossing 1	45 ft.
	Crossing 2	0 ft.
Median: width of median at crossing location		0 ft.
Crossing Width: effective crosswalk width		6 ft.
Raised Median Available?		☐ Yes ☑ No
ADA Compliant Median Available (minimum 4' x 4' landing)?		☐ Yes ☑ No
Curb Ramps Available?		☐ Yes ☑ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?		☐ Yes ☑ No
Speed:	Posted or 85th percentile speed	45 mph
Roadway Curvature and Sight Distances:	Average walking speed	6.2 ft/s
Is the crossing location within a horizontal or vertical curve?		☐ Yes ☑ No

Equations to calculate the following are located on the next page

Direction 1: Stopping Sight Distance (SSD)	360 ft.	provided?	☑ Yes ☐ No
Direction 2: Stopping Sight Distance (SSD)	ft.	provided?	☐ Yes ☐ No
Direction 1: Pedestrian Sight Distance (PedSD)	679 ft.	provided?	☑ Yes ☐ No
Direction 2: Pedestrian Sight Distance (PedSD)	ft.	provided?	☐ Yes ☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:		Daily	8,200	pedestrians:		Daily	
AM Peak	Hourly	508	Pk 15-min	142	Hourly	16	Pk 15-min	6
PM Peak	Hourly	341	Pk 15-min	94	Hourly	15	Pk 15-min	5

Additional Site Characteristics

Lighting:	
Is street lighting present and does it light the crosswalk location?	☐ Yes ☑ No
Crosswalk Pavement Markings: Is the pedestrian crossing currently marked?	☑ Yes ☐ No
What is the condition of the markings?	☐ Excellent ☐ Good ☐ Fair ☑ Poor
Are the markings easily defined?	☐ Yes ☑ No
Do they need replacement?	☑ Yes ☐ No
What is the crosswalk marking pattern?	Continental
Signing: Currently signed at crosswalk?	☑ Yes ☐ No
Currently signed in advance of crosswalk?	☑ Yes ☐ No
Distances?	direction 1: 547 ft. direction 2: 458 ft.
Enhancements: What enhancements are currently at the crossing location?	Trail Crossing signs (text) dir 1: north, dir 2: south
Adjacent Facilities: Distance to nearest marked crosswalk?	2,000 ft.
What pedestrian control devices are present at the nearest adjacent marked crosswalk?	Traffic signal
Distance to nearest all-way stop, roundabout or signalized intersection	2,000 ft.
Could another location serve the same pedestrian crossing movement?	☐ Yes ☑ No
Could another location serve the the movement more effectively?	☐ Yes ☑ No

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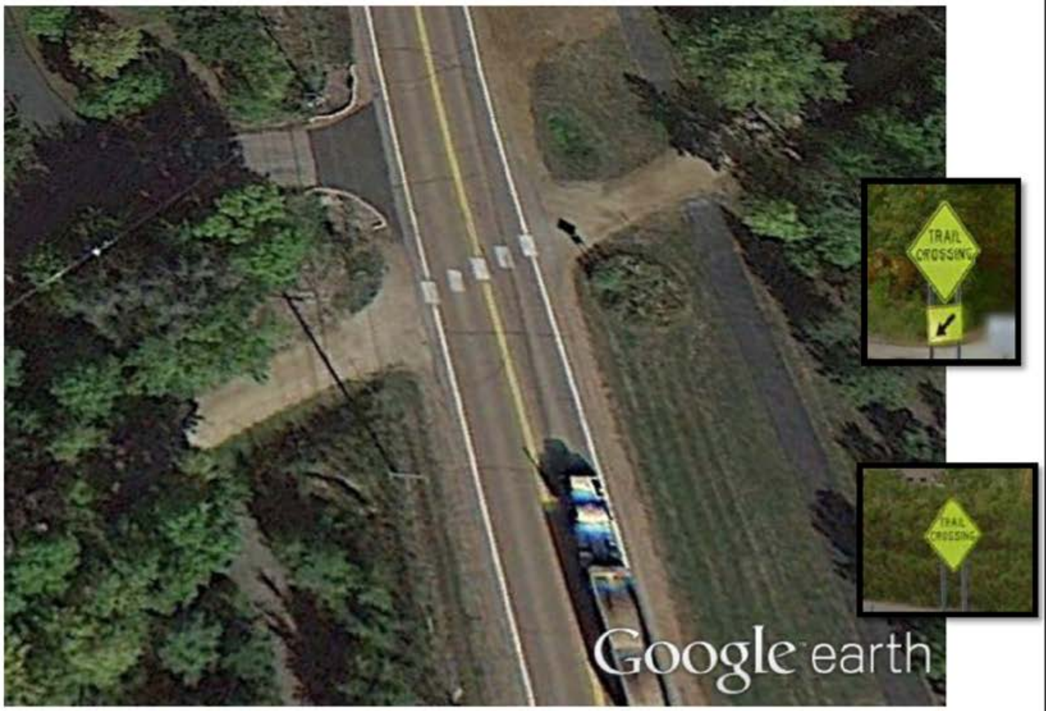
Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: No curb, trail meets roadway at-grade, crossing connects a regional trail, in no passing zone
12' lanes, shoulder 0 to 8' wide,
crosswalk 6' wide, trail 12' wide

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Safety Review

No pedestrian crashes at the location within last ten years. There have been three rear-end crashes at the location within the last ten years.

What does this tell us? Vehicles are stopping, but may be late in stopping. Sight distance may be impaired. Review of location indicates that pedestrians may come out quickly from tree cover.

SSD, PedSD Calculation

The Field Review Worksheet completes this calculation.

$$SSD = d_{PRT} + d_{MT} = 1.47Vt + 1.075\frac{V^2}{a}$$

Where:

$\mathrm{d_{PRT}}$ = driver perception − reaction distance, (ft)

$\mathrm{d_{MT}}$ = braking distance (ft)

V = design speed (mph)

t = brake reaction time (s) [$\mathbf{DEFAULT = 2.5\ sec}$]

a = deceleration rate ($\frac{\mathrm{ft}}{\mathrm{s}^2}$) [$\mathbf{DEFAULT = 11.2\ \frac{\mathit{ft}}{\mathit{s}^2}}$]

$$SSD = 1.47 * 45 * 2.5 + 1.075\frac{45^2}{11.2} = 359.7\ ft\ \approx 360\ ft$$

Evaluation of the crossing indicates that there is sufficient stopping sight distance.

$$PedSD = 1.47V(\frac{L}{S_p} + t_s)$$

Where:

L = length of crossing (ft)

$\mathrm{S_p}$ = average pedestrian walking speed $\left(\frac{\mathrm{ft}}{\mathrm{s}}\right)$ [$\boldsymbol{DEFAULT = 3.5\frac{ft}{s}}$]

t_s = pedestrian start − up and end clearance time (s) [$\mathbf{DEFAULT = 3.0\ sec}$]

Actual pedestrian walking speed collected: average 6.2 ft/s

$$PedSD = 1.47 * 45 * \left(\frac{45}{6.2} + 3.0\right) = 679\ ft$$

Again, evaluation of the crossing indicates that there is sufficient pedestrian sight distance for this crossing. There is approximately 880 ft available to the south, and approximately 860 ft available to the north.

HCM Analysis

Determine inputs:

V = 508 in AM, 341 in PM

Evaluation Inputs:	**defaults:**		**Input Table:**	
L = crosswalk length (ft)			L =	45
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	6.2
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	508
Peak 15-minute volume (veh)				142
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of lanes crossed	N =	INT(L/11)	N =	2

AM Peak Hour

Step 1: Identify Two-Staged Crossings

a. There is no median.
b. There are no curb ramps – There is no curb

Step 2: Determine Critical Headway

Pedestrian Platooning is **NOT** observed, so the spatial distribution of pedestrians can assumed to be 1 (N_p=1, v_p = 0) and the critical headway is determined from the equation below:
Single Pedestrian:

$$t_c = t_{c,G} = \frac{L}{S_p} + t_s$$

$$t_{c,G} = \frac{45}{6.2} + 3.0 = 10.3\ sec$$

Step 3: Estimate Probability of a delayed crossing

Calculate the flow rate (since we have the data, using peak 15-minutes):

$$v = \frac{V}{PHF} = \frac{508}{\frac{508}{4*142}} = \frac{508}{.89} = 568\frac{veh}{hr} = 0.16\ veh/s$$

Calculate the probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)})^N$$

$$P_b = 1 - \ e^{\frac{-10.3(0.16)}{2}} = 0.55$$

$$P_d = 1 - (1 - 0.55)^2 = 0.80$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \ \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \ \frac{d_g}{P_d}$$

$$d_g = \ \frac{1}{0.16}\left(e^{0.16(10.3)} - 0.16(10.3) - 1\right) = 15.4\ sec$$

$$d_{gd} = \ \frac{15.4}{0.56} = 19.2\ sec$$

If there are no additional treatments at the crossing, delay = 19.2 sec. (LOS C)

Delay is acceptable. Location does have high visibility markings and signs but they are in poor condition. The roadway has a speed limit of 45 mph. Little to no yielding is likely due to the presence of the markings and signs. Considered to have no treatments. Go to Step 5 of the flowchart.

Pedestrian Sight Distance

Pedestrian Sight Distance is provided. Based on available data, the crossing does not need any treatments and does not have to be marked or signed.

PM Peak Hour

Same process as AM Peak Hour:

$$Delay = \ 12.3\ sec = LOS\ C$$

Analysis of the crossing indicates that the crossing is experiencing LOS C during the AM Peak Hour and LOS C in the PM Peak Hour. Pedestrian traffic is essentially equal in the AM and PM.

Result

Acceptable Service Level in the AM and PM

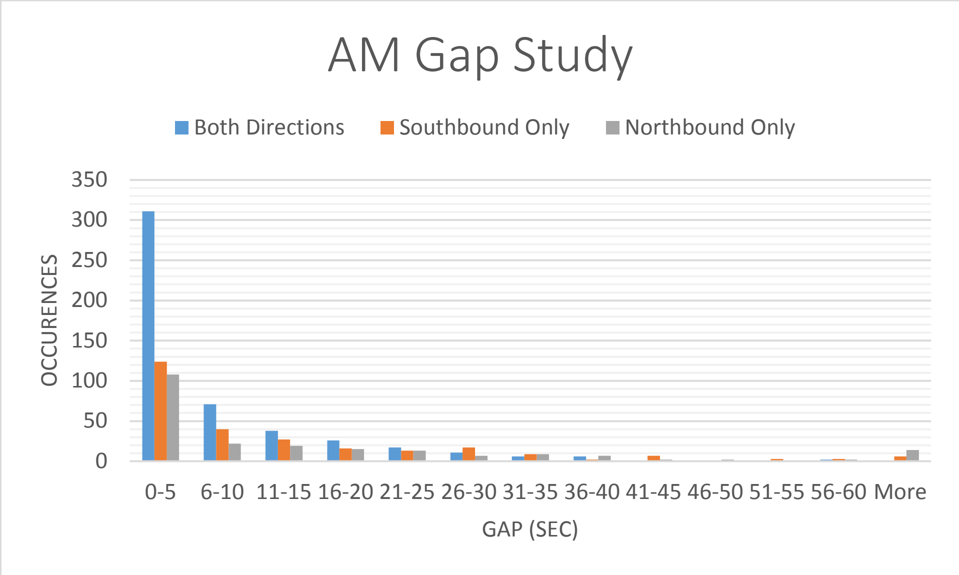
Because there is an acceptable level of service for this crossing, and the PedSD/SSD are met, no changes are recommended at this crossing. Based on the analysis, the signings and markings could be removed but since they are already in place, that can be difficult politically.

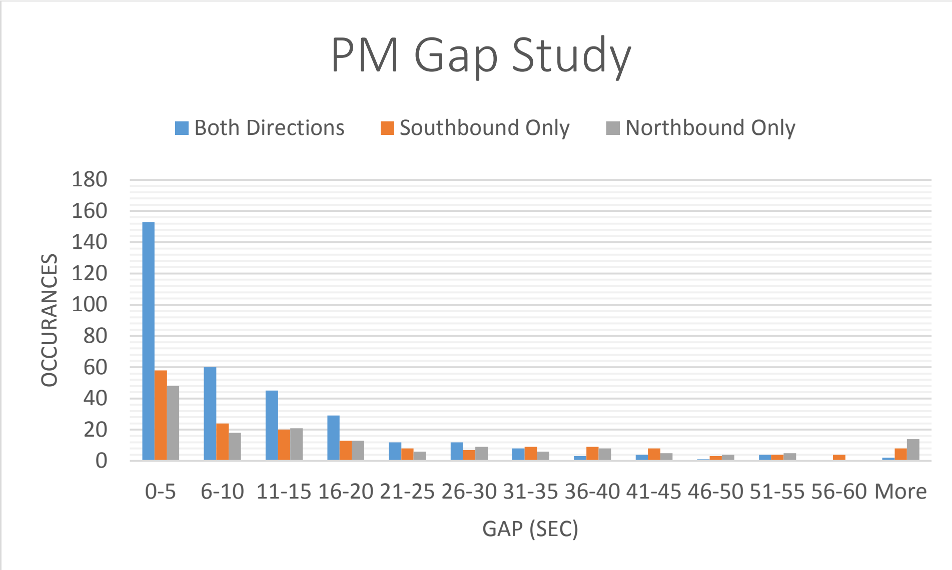
Some recommendations based on the field review.

- The crosswalk markings should be re-applied so that they are effective for traffic.
- The crosswalk markings should be re-marked to match the width of the trail, 12' instead of the standard 6'.
- Trail crossing warning signs should be updated with the most recent version from the MN MUTCD.

How does this compare to a gap study?

Gap Study (If Available)





A gap study can show how much time exists between successive vehicles. This can be used to determine if there are available gaps to cross. As can be seen by these graphs, most of the gaps are very small (0-10 sec) for both directions, meaning these are the gaps available to cross both directions of traffic.

$$\boldsymbol{Needed\ Gap\ = Crossing\ Time + Start/End\ Time = \frac{45}{6.2} + 3 = 10.3\ sec}$$

Check of the data provided in the gap study graph indicates that there are 131 gaps available during the AM peak hour and 137 gaps available during the PM peak hour that meet the needed crossing time of 10.3 seconds. This indicates that there is approximately one acceptable gap every 30 seconds. Generally this would indicate an average wait time of around 15 seconds, close to the results from the HCM analysis.

The HCM evaluation worksheets are provided on the next pages.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 1:Two Lane Rural Highway	Date:	
City, State:	Any City, Minnesota	Scenario:	Trail Crossing, AM Peak Hour
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☐	☑
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐	☑

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	45	t_s =	3	L =		t_s =	
S_p =	6.2	t_c =	10.3	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		t_c =	10.3	v_p =		t_c =	
v =	0.16	N_c =		v =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	6	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	10.3	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	10.3			$t_{c,G}$ =			
v =	0.16	P_b =	0.56	v =		P_b =	
N =	2	P_d =	0.8	N =		P_d =	

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Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	10.26			$t_{c,G}$ =			
v =	0.16	d_g =	15.42	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	15.42			d_g =			
P_d =	0.80	d_{gd} =	19.22	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	19.2
LOS	C

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 1:Two Lane Rural Highway	Date:	
City, State:	Any City, Minnesota	Scenario:	Trail Crossing, PM Peak Hour
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☐	☑
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐	☑

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	45	t_s =	3	L =		t_s =	
S_p =	6.2	t_c =	10.3	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		t_c =	10.3	v_p =		t_c =	
v =	0.1	N_c =		v =		N_c =	

2. compute spatial distribution:

$$N_p = \mathrm{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	6	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	10.3	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	10.3			$t_{c,G}$ =			
v =	0.1	P_b =	0.41	v =		P_b =	
N =	2	P_d =	0.66	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1		crossing 2	
$t_{c,G}$ = 10.26		$t_{c,G}$ =	
v = 0.10	d_g = 8.07	v =	d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1		crossing 2	
d_g = 8.071		d_g =	
P_d = 0.66	d_{gd} = 12.304	P_d =	d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j
M_y = motorist yield rate (decimal) M_y =

crossing 1		crossing 2	
h =	n =	h =	n =
	d_p =		d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

2. Two-Lane Crossing

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	12.3
LOS	C

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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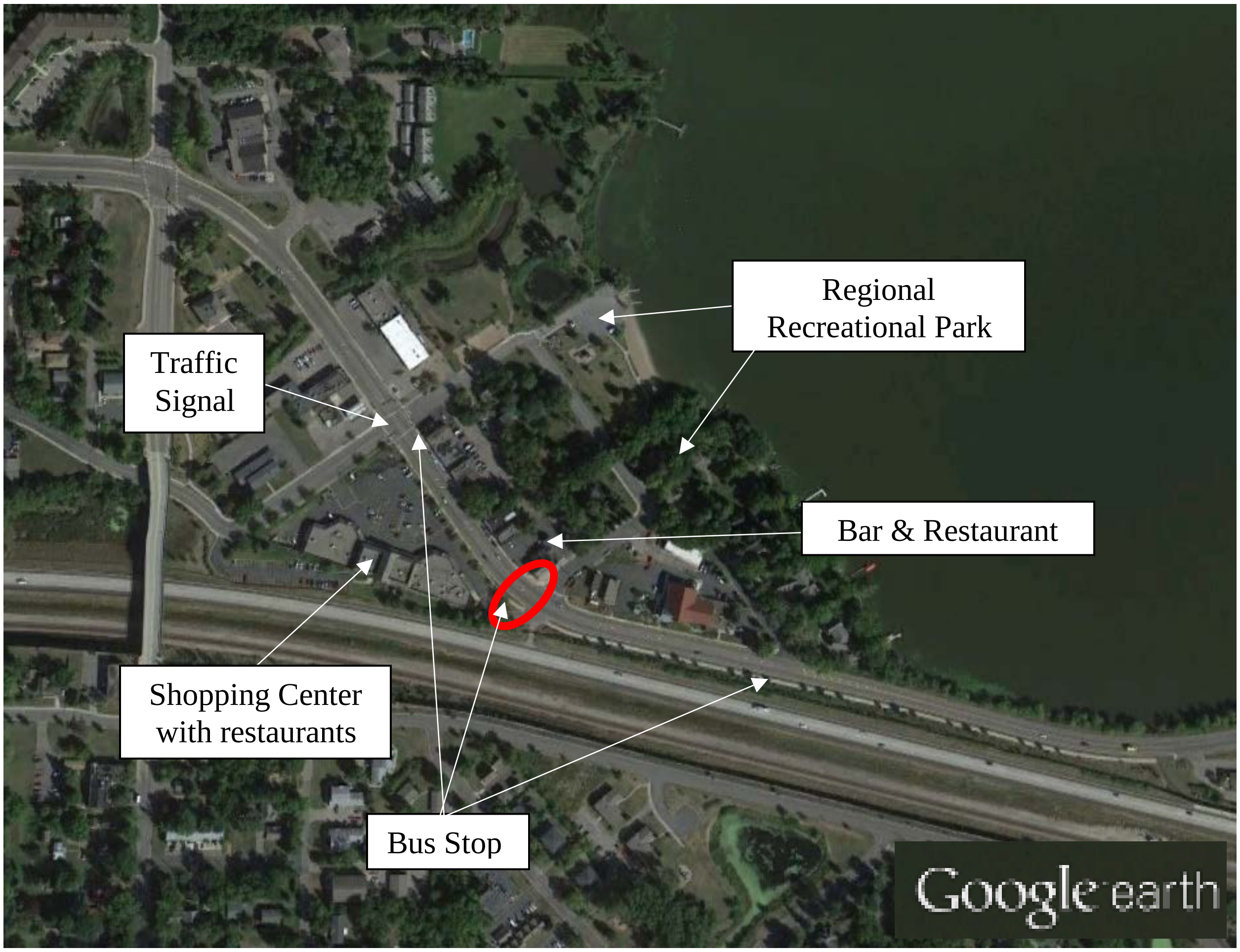
Example 2: Two-Lane Urban Street Crossing

Site Review

Conduct a field review and take pedestrian/vehicle counts during the peak hours.



The crossing is currently unmarked and there is a bus stop at the crossing location.

Complete Field Review Worksheet.

LRRB

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Two Lane Urban Street	Date:	
City, State:	Any City, Minnesota	Scenario:	Saturday, Noon
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.
- Crossing 1: 66 ft.
- Crossing 2: 0 ft.

Median: width of median at crossing location: 0 ft.

Crossing Width: effective crosswalk width: 8 ft.

Raised Median Available?	☐ Yes	☐ No
ADA Compliant Median Available (minimum 4' x 4' landing)?	☐ Yes	☐ No
Curb Ramps Available?	☐ Yes	☐ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?	☐ Yes	☐ No

Speed: Posted or 85th percentile speed: 30 mph

Roadway Curvature and Sight Distances: Average walking speed: 3.5 ft/s

Is the crossing location within a horizontal or vertical curve? ☑ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	197 ft.	provided?	☑ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	964 ft.	provided?	☐ Yes	☑ No
Direction 2:	Pedestrian Sight Distance (PedSD)	ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:				pedestrians:			
			Daily	10,400			Daily	
AM Peak	Hourly		Pk 15-min		Hourly		Pk 15-min	
PM Peak	Hourly	690	Pk 15-min	219	Hourly	3	Pk 15-min	3

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☑ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern?

Signing: Currently signed at crosswalk? ☐ Yes ☑ No

Currently signed in advance of crosswalk? ☐ Yes ☑ No

Distances? direction 1 ft. direction 2 ft.

Enhancements: What enhancements are currently at the crossing location?

Adjacent Facilities: Distance to nearest marked crosswalk? 515 ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? Traffic Signal

Distance to nearest all-way stop, roundabout or signalized intersection: 515 ft.

Could another location serve the same pedestrian crossing movement? ☑ Yes ☐ No

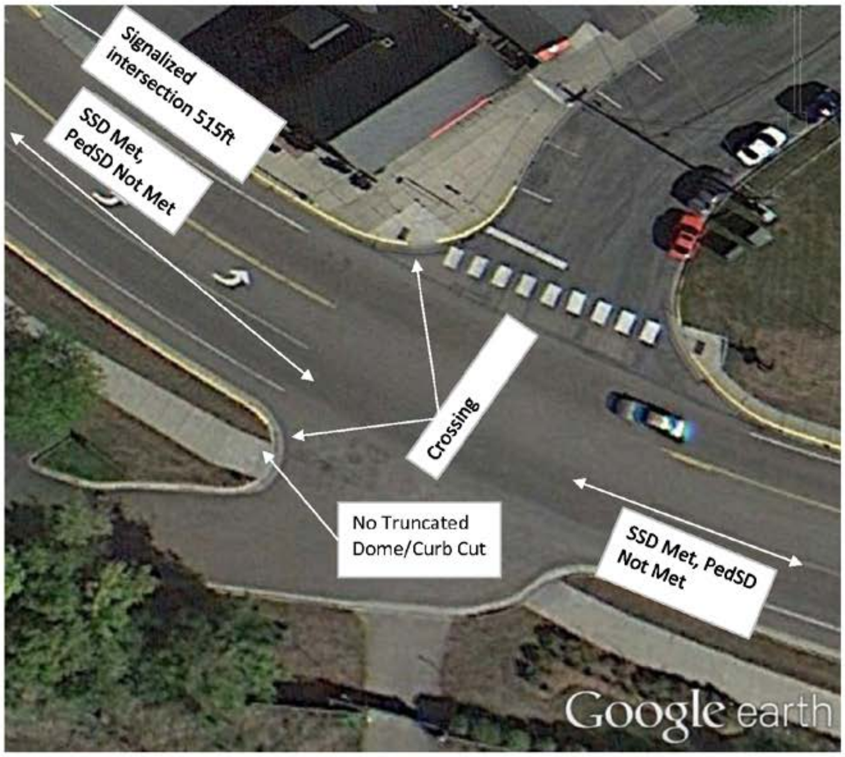
Could another location serve the the movement more effectively? ☐ Yes ☑ No

Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Crossing location unmarked, no effective curb ramps, lighting on north corner
no pedestrian crossing signing

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Safety Review
No pedestrian crashes at the location within last ten years. Two run off road crashes near the intersection in past ten years.

No safety issues indicated by crash data.

SSD, PedSD Calculation

$$SSD = d_{PRT} + d_{MT} = 1.47Vt + 1.075\frac{V^2}{a}$$

Where:
$\mathrm{d_{PRT}} = \text{driver perception} - \text{reaction distance, (ft)}$
$\mathrm{d_{MT}} = \text{braking distance (ft)}$
$\mathrm{V} = \text{design speed (mph)}$
$\mathrm{t} = \text{brake reaction time (s)}\ [\mathbf{DEFAULT = 2.5\ sec}]$
$\mathrm{a} = \text{deceleration rate}\ (\frac{\mathrm{ft}}{\mathrm{s}^2})\ [\mathbf{DEFAULT = 11.2}\ \boldsymbol{\frac{ft}{s^2}}]$

$$SSD = 1.47 * 30 * 2.5 + 1.075\frac{30^2}{11.2} = 197\ ft$$

Looking at a map of the crossing, there is sufficient stopping sight distance for this crossing.

$$PedSD = 1.47V(\frac{L}{S_p} + t_s)$$

Where:
$L = \text{length of crossing (ft)}$
$\mathrm{S_p} = \text{average pedestrian walking speed}\ \left(\frac{\mathrm{ft}}{\mathrm{s}}\right)\ [\boldsymbol{DEFAULT = 3.5\frac{ft}{s}}]$
$\mathrm{t}_s = \text{pedestrian start} - \text{up and clearance time (s)}\ [\mathbf{DEFAULT = 3.0\ sec}]$

$$PedSD = 1.47 * 30 * \left(\frac{66}{3.5} + 3\right) = 964\ ft$$

Looking at a map of the crossing, there is not sufficient pedestrian sight distance. There is approximately 400 to 500 ft ft available to the east, and approximately 1,200 to 1,400 ft available to the northwest.

HCM Analysis

Determine inputs:

Evaluation Inputs:

L = crosswalk length (ft)

S_p = average pedestrian walking speed (ft/s)

t_s = pedestrian start-up and end clearance time (s)

V = vehicular hourly volume (veh/hr)

Peak 15-minute volume (veh)

v_p = pedestrian flow rate (ped/s)

W_c = crosswalk width (ft)

N = number of lanes crossed

defaults:	
S_p =	3.5
t_s =	3.0
v_p =	0*
W_c =	8.0
N =	INT(L/11)

Input Table:	
L =	66
S_p =	3.5
t_s =	3
V =	690
	219
v_p =	0
W_c =	8
N =	2

Weekend Midday Peak Hour

Step 1: Identify Two-Staged Crossings

There is no median at the crosswalk. This is a one-stage crossing

Step 2: Determine Critical Headway

Pedestrian Platooning is **NOT** observed, so the spatial distribution of pedestrians can assumed to be 1 (N_p=1, v_p = 0) and the critical headway is determined from the equation below:

Single Pedestrian:

$$t_c = t_{c,G} = \frac{L}{S_p} + t_s$$

$$t_{c,G} = \frac{66}{3.5} + 3.0 = 21.9\ sec$$

Step 3: Estimate Probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)})^N$$

$$v = \frac{V}{PHF} = \frac{690}{\frac{690}{4*219}} = 876\frac{veh}{hr} = 0.24\ veh/s$$

$$P_b = 1 - e^{\frac{-21.9(0.24)}{2}} = 0.93$$

$$P_d = 1 - (1 - 0.93)^2 = 0.99$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \frac{d_g}{P_d}$$

$$d_g = \frac{1}{0.24}\left(e^{0.24(21.9)} - 0.24(21.9) - 1\right) = 765\ sec$$

$$d_{gd} = \frac{764}{0.99} = 769\ sec$$

There is no reduction in delay due to yielding vehicles

$$d_p = d_{gd} = 769\ sec = LOS\ F$$

Analysis of the crossing indicates that the crossing is experiencing LOS F the Midday Peak Hour.

Result: Unacceptable Service Level. **Skip to Step 6 of the evaluation flowchart.**

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

LRRB

Crossing Location:	Example 2: Two Lane Urban Street	Date:	
City, State:	Any City, Minnesota	Scenario:	Saturday, noon
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☐ Yes	☑ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☑ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☑ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	66	t_s =	3	L =		t_s =	
S_p =	3.5	t_c =	21.9	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	21.9	υ_p =		t_c =	
υ =	0.24	N_c =		υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	21.9	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	21.9			$t_{c,G}$ =			
υ =	0.24	P_b =	0.93	υ =		P_b =	
N =	2	P_d =	0.99	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}(e^{v t_{c,G}} - v t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	21.86			$t_{c,G}$ =			
v =	0.24	d_g =	764.61	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	764.6			d_g =			
P_d =	0.995	d_{gd} =	768.66	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_{1})_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

Summary	
Average	768.7
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Review Origins and Destination, Alternate Routes

Origins and Destinations

The crossing is at a location that connects restaurants to a regional recreational park. Crossing also connects multiple restaurants and bus stops.

Alternative Routes

There may be an alternative route to use the signalized intersection based on where pedestrians are in the park, but may not be an alternative for some.

Calculate how much time it would take for a pedestrian to walk to the nearest adjacent marked crossing, cross the roadway, and return to the location where they started.

This total amount of time is compared to the average pedestrian delay (average measured wait time).

Distance to nearest marked crossing = 505 ft to the northwest (Signalized intersection)

Walking Time to Signalized Intersection:

$$\frac{505\ ft}{3.5\frac{ft}{s}} = 144\ sec$$

Wait Time and Crossing Time at Intersection:
Assume average wait time of 30 sec.

$$30 + \frac{65\ ft}{3.5\frac{ft}{s}} = 49\ sec$$

Walking Time back to Original Location:

$$\frac{505\ ft}{3.5\frac{ft}{s}} = 144\ sec$$

Total Time:

$$144 + 49 + 144 = 337\ sec$$

Average Measured Wait Time (Pedestrian Delay) without a crossing

769 sec with current crossing $(from\ HCM\ Analysis)$

The alternative route time is considerably less than the average wait time at the current crossing. Pedestrians should be encouraged to use the crossing at the signalized intersection to cross the roadway. However, there is a direct origin-destination connection between the southeast end of the Park and the shopping center/restaurants.

Result: There could be an acceptable alternative route at the signalized intersection, but there is a direct origin-destination connection at the crossing.

Access Spacing and Functional Classification
The crossing is not located in a signalized corridor or grade-separated facility.

Speed and Pedestrian Use
The speed limit is 30 mph, but the city population is less than 10,000.

There were 3 pedestrians during the peak hour.

Result: **Go to Step 10 of the evaluation flowchart.**

School Crossing
This is not a school crossing, **go to Step 9**.

FHWA Safety Guidance
Three lanes, speed limit = 30 mph, ADT = 10,400. Results in C designation. **Go to Step 11, Traffic Calming Treatments**.

Traffic Calming Treatment Options
Treatment Options should consider the roadway environment.

a. Urban section (curb)
b. Two-Lane Undivided with left turn lanes
c. Speed Limit = 30 mph
d. Origin-Destination connection
e. Clear motorist sight lines (SSD is met)
f. Pedestrian sight lines impacted (PedSD not met)
g. Crossing is not currently signed and marked
h. No pedestrian crashes reported in past 10 years

Review the Traffic Calming Treatment options that are available.

a. Center Median with Refuge Island – possible, remove shoulder, traffic to curb
b. Raised Crossing – possible, but difficult with the curve
c. Lighting – already implemented
d. Pavement Striping – already two-lane section
e. Curb Bump-Out/Extensions – possible
f. Channelized Turn Lanes – not recommended

Due to the low pedestrian volume collected at the site, the biggest need is to increase the pedestrian sight distance, but that would require extensive reconstruction and/or property acquisition. There is an alternative route at the signal that is recommended. Pedestrian walkway enhancements to get people to use that crossing location is recommended.

Based on the traffic calming treatment options, the curb bump-outs would likely be the easiest to implement, would not obstruct the travel lanes, and would reduce the crossing length. Uncontrolled crossing treatments are not recommended due to the low pedestrian count. No other changes should be considered at the existing crossing besides advanced warning signs to alert motorists of the chance of pedestrians crossing.

Curb bump-outs plus lane narrowing and moving the crossing further north could reduce the crossing length to 38’ (2-11’ lanes, 12’ turn lane, 2’ curb reaction).

Repeat Step 4

Determine inputs:

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	38
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	3.5
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	690
Peak 15-minute volume (veh)				219
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8
N = number of through lanes crossed	N =	INT(L/11)	N =	2

Weekend Midday Peak Hour

Step 1: Identify Two-Staged Crossings

There is no median at the crosswalk. This is a one-stage crossing

Step 2: Determine Critical Headway

Pedestrian Platooning is **<u>NOT</u>** observed, so the spatial distribution of pedestrians can assumed to be 1 (N_p=1, v_p = 0) and the critical headway is determined from the equation below:
Single Pedestrian:

$$t_c = t_{c,G} = \frac{L}{S_p} + t_s$$

$$t_{c,G} = \frac{38}{3.5} + 3.0 = 13.9\ sec$$

Step 3: Estimate Probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)})^N$$

$$v = \frac{V}{PHF} = \frac{690}{\frac{690}{4 * 219}} = 876\frac{veh}{hr} = 0.24\, veh/s$$

$$P_b = 1 - e^{\frac{-13.9(0.24)}{2}} = 0.81$$

$$P_d = 1 - (1 - 0.81)^2 = 0.96$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \frac{d_g}{P_d}$$

$$d_g = \frac{1}{0.24}\left(e^{0.24(13.9)} - 0.24(13.9) - 1\right) = 98\, sec$$

$$d_{gd} = \frac{98}{0.96} = 102\, sec$$

There is no reduction in delay due to yielding vehicles

$$d_p = d_{gd} = 102\, sec = LOS\ F$$

Analysis of the crossing with the curb bump-outs could reduce the crossing delay by 667 seconds or by 85%. The curb bump-outs would also increase the visibility of any pedestrian to oncoming vehicles.

<u>Result</u>
Still unacceptable Service Level. Could consider do nothing, just add the curb bump-outs, or consider appropriate high level treatments. Pedestrian count too low for high level treatments.

Recommendation: Consider curb bump-outs or do nothing.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 2: Two Lane Urban Street	Date:	
City, State:	Any City, Minnesota	Scenario:	Saturday, noon, Curb Bump-Outs
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☐	☑
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐	☑

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	38	t_s =	3	L =		t_s =	
S_p =	3.5	t_c =	13.9	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		t_c =	13.9	v_p =		t_c =	
v =	0.24	N_c =		v =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	13.9	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.9			$t_{c,G}$ =			
v =	0.24	P_b =	0.81	v =		P_b =	
N =	2	P_d =	0.96	N =		P_d =	

Developed by Bolton Menk, Inc.
for the Local Road Research Board.

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.86			$t_{c,G}$ =			
v =	0.24	d_g =	97.888	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	97.89			d_g =			
P_d =	0.964	d_{gd} =	101.54	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	101.5
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Developed by Bolton Menk, Inc.
for the Local Road Research Board.

Example 3: Four-Lane Divided Urban Street Crossing

<u>Site Review</u>
Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is currently marked and signed. There is a median along the street but the median does not extend through the crossing location. There are two senior living facilities, a community/recreational center, and bus stops within walking distance of the crossing.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 3: Four-Lane Divided Street	Date:	
City, State:	Any City, Minnesota	Scenario:	
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.	Crossing 1	112	ft.
	Crossing 2		ft.
Median: width of median at crossing location			ft.
Crossing Width: effective crosswalk width		6	ft.
Raised Median Available?		☑ Yes	☐ No
ADA Compliant Median Available (minimum 4' x 4' landing)?		☐ Yes	☑ No
Curb Ramps Available?		☑ Yes	☐ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?		☑ Yes	☐ No
Speed:	Posted or 85th percentile speed	35	mph
Roadway Curvature and Sight Distances:	Average walking speed	4.8	ft/s
Is the crossing location within a horizontal or vertical curve?		☐ Yes	☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	246 ft.	provided?	☑ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	1355 ft.	provided?	☐ Yes	☑ No
Direction 2:	Pedestrian Sight Distance (PedSD)	ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:		Daily	15,000	pedestrians:		Daily	
AM Peak	Hourly	948	Pk 15-min	262	Hourly	6	Pk 15-min	3
PM Peak	Hourly	841	Pk 15-min	227	Hourly	6	Pk 15-min	3

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location?	☑ Yes	☐ No
Crosswalk Pavement Markings: Is the pedestrian crossing currently marked?	☑ Yes	☐ No
What is the condition of the markings? ☐ Excellent ☑ Good	☐ Fair	☐ Poor
Are the markings easily defined?	☑ Yes	☐ No
Do they need replacement?	☐ Yes	☑ No
What is the crosswalk marking pattern?	Continental	
Signing: Currently signed at crosswalk?	☑ Yes	☐ No
Currently signed in advance of crosswalk?	☑ Yes	☐ No
Distances? direction 1: 527 ft.	direction 2: 478 ft.	
Enhancements: What enhancements are currently at the crossing location?	Signs and High Visibility Markings	
Adjacent Facilities: Distance to nearest marked crosswalk?	905 ft.	
What pedestrian control devices are present at the nearest adjacent marked crosswalk?	Traffic signal	
Distance to nearest all-way stop, roundabout or signalized intersection	905 ft.	
Could another location serve the same pedestrian crossing movement?	☐ Yes	☑ No
Could another location serve the the movement more effectively?	☐ Yes	☑ No

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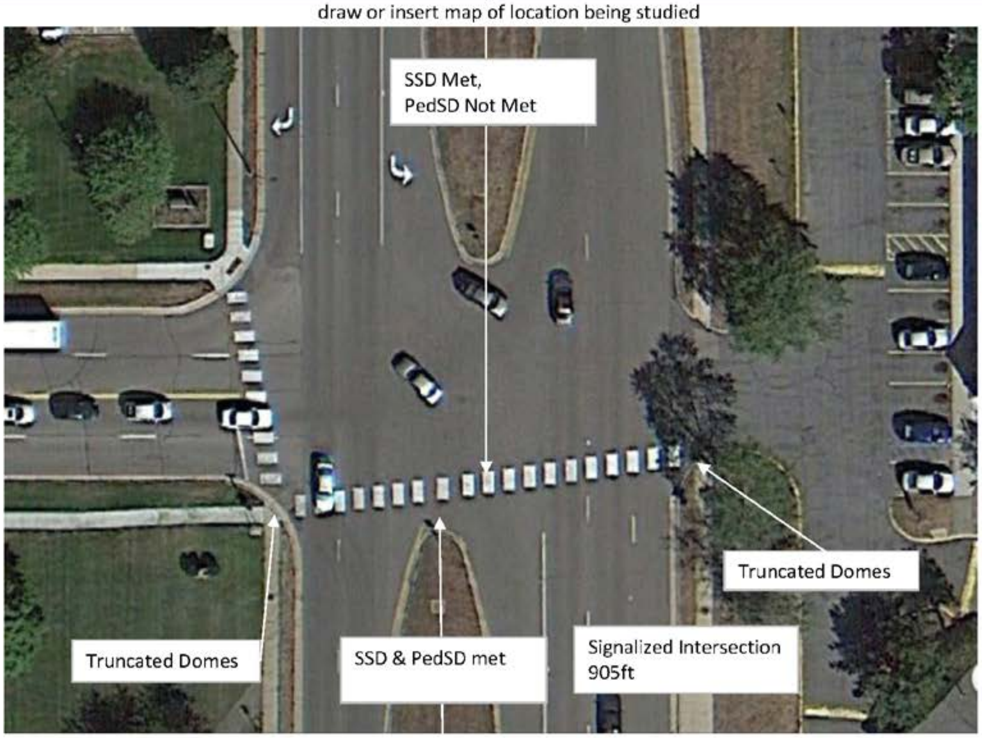
Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Many O-D connections, ped crossings signs present and in good condition.
Curb ramps have recently been updated.

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Safety Review

There were two pedestrian crashes at the location within the last ten years (2004 & 2009). The 2004 crash resulted in a pedestrian fatality. There have been a total of 14 crashes at this location over the last ten years. Most having to do with turning vehicles. Many turning movements and lanes to keep track of in addition to the pedestrians.

SSD, PedSD Calculation

$$SSD = d_{PRT} + d_{MT} = 1.47Vt + 1.075\frac{V^2}{a}$$

Where:

$\mathrm{d_{PRT}}$ = driver perception − reaction distance, (ft)

$\mathrm{d_{MT}}$ = braking distance (ft)

V = design speed (mph)

t = brake reaction time (s) [**DEFAULT = 2.5 sec**]

a = deceleration rate ($\frac{\mathrm{ft}}{\mathrm{s}^2}$) [**DEFAULT = 11.2** $\boldsymbol{\frac{ft}{s^2}}$]

$$SSD = 1.47 * 35 * 2.5 + 1.075\frac{35^2}{11.2} = 246.2\,ft \approx 246\,ft$$

Looking at a map of the crossing, there is sufficient stopping sight distance for this crossing.

$$PedSD = 1.47V(\frac{L}{S_p} + t_s)$$

Where:

L = length of crossing (ft)

$\mathrm{S_p}$ = average pedestrian walking speed $\left(\frac{\mathrm{ft}}{\mathrm{s}}\right)$ [$\boldsymbol{DEFAULT = 3.5\frac{ft}{s}}$]

t_s = pedestrian start − up and clearance time (s) [**DEFAULT = 3.0 sec**]

$$PedSD = 1.47 * 35 * \left(\frac{112}{4.8} + 3\right) = 1{,}355\,ft$$

Again, looking at a map of the crossing, there is not sufficient pedestrian sight distance. There is approximately 1,000 to 1,200 ft available to the north, and approximately 1,400 to 1,600 ft available to the south.

HCM Analysis

Determine inputs:

V = 948 in AM peak hour, 841 in PM peak hour

Evaluation Inputs:	**defaults:**		**Input Table:**	
L = crosswalk length (ft)			L =	112
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.8
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	948
Peak 15-minute volume (veh)				262
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6
N = number of through lanes crossed	N =	INT(L/11)	N =	4

AM Peak Hour

Step 1: Identify Two-Staged Crossings

There is a median, but it does not extend to the crossing location. This is a one-stage crossing.

Step 2: Determine Critical Headway

Pedestrian Platooning is **NOT** observed, so the spatial distribution of pedestrians can assumed to be 1 (N_p=1, v_p = 0) and the critical headway is determined from the equation below:

Single Pedestrian:

$$t_c = t_{c,G} = \frac{L}{S_p} + t_s$$

$$t_{c,G} = \frac{112}{4.8} + 3.0 = 26.3\ sec$$

Step 3: Estimate Probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)})^N$$

N = 4 lanes

$$v = \frac{V}{PHF} = \frac{948}{\frac{948}{4*262}} = 1048\frac{veh}{hr} = 0.29\,veh/s$$

$$P_b = 1 - e^{\frac{-26.3(0.29)}{4}} = 0.85$$

$$P_d = 1 - (1 - 0.85)^4 = 1.00$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \frac{d_g}{P_d}$$

$$d_g = \frac{1}{0.29}\left(e^{0.29(26.3)} - 0.29(26.3) - 1\right) = 7{,}118\,sec$$

$$d_{gd} = \frac{7{,}118}{1.00} = 7{,}121\ (rounding\ error)$$

Delay = 7,118 seconds, LOS F

Step 5: Estimate Delay Reduction due to Yielding Vehicles

M_y= 20% because the crossing has high visibility markings and signs at speed limit of 35 mph.

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P\left(Y_{i)}\right) + [P_d - \sum_{i=1}^{n} P(Y_i)] * d_{gd}$$

$$h = \frac{N}{v} = \frac{4}{0.29} = 13.8$$

$$n = Int\left(\frac{d_{gd}}{h}\right) = Int\left(\frac{7{,}118}{13.8}\right) = 516$$

4-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_{j)})] * [\frac{{P_b}^4 {M_y}^4 + 4{P_b}^3(1-P_b){M_y}^3) + 6{P_b}^2(1-P_b)^2{M_y}^2) + 4P_b(1-{P_b}^3)M_y}{P_d}]$$

$$P(Y_1) = 0.2679$$
$$P(Y_2) = 0.1961$$
$$\ldots$$

Plug these into equation above to determine average pedestrian delay.

$$d_p = \sum_{i=1}^{516} 13.8(i-0.5)P(Y_i) + [1 - \sum_{i=1}^{516} P(Y_i)] * 7{,}121 = 44.5\ sec$$

$$44.5\ sec = LOS\ E$$

Delay is unacceptable, **go to Step 6 of the evaluation flowchart**. There are high visibility markings that are in good condition at the crossing.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location:	Example 3: Four Lane Divided Street	Date:	
City, State:	Any City, Minnesota	Scenario:	AM Peak Hour
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☑ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☑ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	112	t_s =	3	L =		t_s =	
S_p =	4.8	t_c =	26.3	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon)e^{(\upsilon_p - \upsilon)t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	26.3	υ_p =		t_c =	
υ =	0.29	N_c =		υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c-1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	6	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p-1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	26.3	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1-P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	26.3			$t_{c,G}$ =			
υ =	0.29	P_b =	0.85	υ =		P_b =	
N =	4	P_d =	1	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{\upsilon}(e^{\upsilon t_{c,G}} - \upsilon t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
υ = vehicular flow rate across crossing (veh/s)

crossing 1			crossing 2		
$t_{c,G}$ =	26.33		$t_{c,G}$ =		
υ =	0.29	d_g = 7117.9	υ =		d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1			crossing 2		
d_g =	7118		d_g =		
P_d =	1	d_{gd} = 7121.3	P_d =		d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/υ
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	13.8	n =	516	h =	#####	n =	######
		d_p =	44.5			d_p =	######

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 20%

$$P(Y_{i=1}) = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2 \qquad P(Y_{i>1}) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

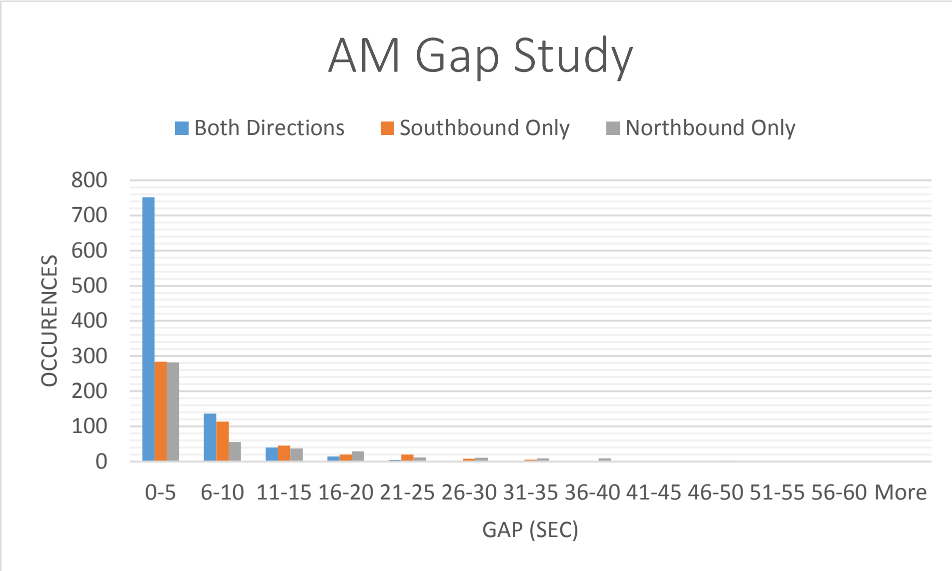
Summary	
Average	44.5
LOS	E

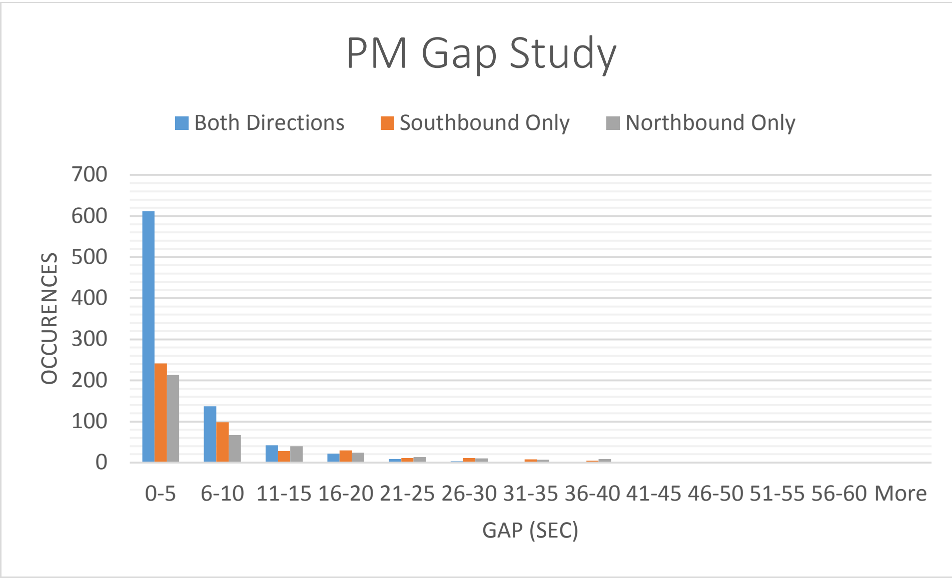
Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

How does this compare to a gap study?

Gap Study (If Available)





A gap study can show how much time exists between successive vehicles. This can be used to determine if there are available gaps to cross. As can be seen by these graphs, most of the gaps are very small (0-10 sec) for both directions, meaning these are the gaps available to cross both directions of traffic.

$$\boldsymbol{Needed\ Gap\ = Crossing\ Time + Start/End\ Time = \frac{112}{4.8} + 3.0 = 26.3\ sec}$$

Check of the data provided in the gap study graph indicates that there are 4 gaps available during the AM peak hour and 5 gaps available during the PM peak hour that meet the needed crossing time of 26.3 seconds. This indicates that there is approximately one acceptable gap every 15 minutes.

Additionally, the median may provide a stopping point for some pedestrians.

- AM Peak, Southbound, 143 gaps available for a needed gap of 8.2 seconds
- AM Peak, Northbound, 97 gaps available for a needed gap of 13.8 seconds
- PM Peak, Southbound, 127 gaps available for a needed gap of 8.2 seconds
- PM Peak, Northbound, 88 gaps available for a needed gap of 13.8 seconds

Consequently, one adequate gap every 1.5 minutes in the AM and PM.

<u>Review Origins and Destinations, Alternate Routes</u>

Origins and Destinations

The crossing is at a location connecting high density residential, retirement communities, bus stops and a community/recreational center. This is a direct connection and most pedestrians will not choose a different crossing location.

Alternative Route Analysis

Calculate how much time it would take for a pedestrian to walk to the nearest adjacent marked crossing, cross the roadway, and return to the location where they started.
This total amount of time will be compared to the average pedestrian delay (average measured wait time).

Distance to nearest marked crossing = 905 ft to the south (Signalized intersection)

Walking Time to Signalized Intersection:

$$\frac{905\ ft}{4.8\frac{ft}{s}} = 189\ sec$$

Wait Time and Crossing Time at Intersection:

Assume average wait time of 30 sec.

$$30 + \frac{125\ ft}{4.8\frac{ft}{s}} = 56\ sec$$

Walking Time to Original Location:

$$\frac{905\ ft}{4.8\frac{ft}{s}} = 189\ sec$$

Total Time:

$$189 + 56 + 189 = 434\ sec$$

Average wait time from HCM analysis is 45 seconds. Crossing time faster at the crossing.

Result: There could be acceptable alternative routes, but most pedestrians will not use them.

Pedestrian Crossing in a Coordinated Signalized Corridor?
The crossing is along a signalized corridor, but is adequately spaced from the adjacent signalized intersections. **Go to Step 8 of the evaluation flowchart.**

Speed and Pedestrian Use
The speed limit is 35 mph, the population is over 10,000, but the crossing location is at a major transit stop. This transit stop is in a densely populated area and therefore can be considered a major stop.

There were 6 pedestrians during the AM peak hour and 6 pedestrians during the PM peak hour.

Result: **Skip to Step 10 of the evaluation flowchart.** Consider traffic calming treatments with or without uncontrolled crossing treatments.

School Crossing
This is not a school crossing, **go to Step 9**.

FHWA Safety Guidance
Multi-lane with raised median, speed limit = 35 mph, ADT = 15,000. Results in P designation. **Go to Step 11, Traffic Calming Treatments**.

Traffic Calming Treatment Options
Treatment Options should consider the roadway environment.

a. Urban section (curb)
b. Four-Lane divided
c. Speed Limit = 35 mph
d. Crossing location connects residential areas to bus stop/community center
e. Clear motorist sight lines (SSD is met)
f. Pedestrian sight lines impacted (PedSD not met)
g. Crossing is currently signed and marked
h. Two pedestrian crashes reported in past 10 years (One fatal).

Review the Traffic Calming Treatment options that are available.

a. Center Median with Refuge Island – possible, extend median through crossing
b. Raised Crossing – not recommended due to traffic volume
c. Lighting – already lit

d. Pavement Striping – possible but difficult to implement without extensive work
e. Curb Bump-Out/Extensions – possible, but does not fit roadway
f. Channelized Turn Lanes – not recommended

Based on the existing options, the center median with the refuge island is the most reasonable for this situation because there is already a median installed that doesn't extend to the crosswalk.

Repeat Step 4 of the evaluation flowchart.

<u>HCM Analysis</u>
Determine inputs:

V = 948 in AM peak hour, 841 in PM peak hour

Evaluation Inputs:	**defaults:**		**Input Table:**	
L = crosswalk length (ft) – east side			L =	52
L = crosswalk length (ft) – west side			L =	25
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.8
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr) – east side			V =	524
V = vehicular hourly volume (veh/hr) – west side			V =	424
Peak 15-minute volume (veh) – east side				150
Peak 15-minute volume (veh) – west side				112
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6
N = number of lanes crossed – east side	N =	INT(L/11)	N =	2
N = number of lanes crossed – west side	N =	INT(L/11)	N =	2

AM Peak Hour

Step 1: Identify Two-Staged Crossings

This is now a two-stage crossing.

Step 2: Determine Critical Headway

Pedestrian Platooning is <u>**NOT**</u> observed, so the spatial distribution of pedestrians can assumed to be 1 (N_p=1, v_p = 0) and the critical headway is determined from the equation below:

Single Pedestrian:

$$t_c = t_{c,G} = \frac{L}{S_p} + t_s$$

$$t_{c,G} = \frac{52}{4.8} + 3.0 = 13.8\ sec$$

$$t_{c,G} = \frac{25}{4.8} + 3.0 = 8.2\ sec$$

Step 3: Estimate Probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)})^N$$

N = 2 lanes

$$v = \frac{V}{PHF} = \frac{524}{\frac{524}{4*150}} = 600\frac{veh}{hr} = 0.17\ veh/s$$

$$v = \frac{V}{PHF} = \frac{424}{\frac{424}{4*112}} = 448\frac{veh}{hr} = 0.12\ veh/s$$

$$P_b = 1 - e^{\frac{-13.8(0.17)}{2}} = 0.69 \qquad P_b = 1 - e^{\frac{-8.2(0.12)}{2}} = 0.39$$

$$P_d = 1 - (1 - 0.69)^2 = 0.90 \qquad P_d = 1 - (1 - 0.39)^2 = 0.63$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \frac{d_g}{P_d}$$

$$d_g = \frac{1}{0.17}\left(e^{0.17(13.8)} - 0.17(13.8) - 1\right) = 42\ sec$$

$$d_g = \frac{1}{0.12}\left(e^{0.12(8.2)} - 0.12(8.2) - 1\right) = 6\ sec$$

$$d_{gd} = \frac{42}{0.90} = 46\,\mathrm{sec} \qquad d_{gd} = \frac{6}{0.63} = 9\,\mathrm{sec}$$

Delay = 55 seconds, LOS F

There is delay reduction. M_y= 17% because the crossing has high visibility markings and signs at 35 mph, but is now a staged crossing. As there is already a median along the roadway, it is anticipated that extension of the median would have little to no effect on motorist yielding.

$$d_p = \sum_{i=1}^{n} h(i-0.5)P\big(Y_{i)}\big) + [P_d - \sum_{i=1}^{n} P(Y_i)] * d_{gd}$$

$$h = \frac{N}{v} = \frac{2}{0.17} = 11.8 \qquad h = \frac{N}{v} = \frac{2}{0.12} = 16.7$$

$$n = Int\left(\frac{d_{gd}}{h}\right) = Int\left(\frac{46}{11.8}\right) = 3 \qquad n = Int\left(\frac{d_{gd}}{h}\right) = Int\left(\frac{9}{16.7}\right) = 0, but\ must\ be > 0, = 1$$

2-Lane Crossing – east side

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P\big(Y_j\big)\right]\left[\frac{\big(2P_b(1-P_b)M_y\big) + \ \big(P_b{}^2 M_y{}^2\big)}{P_d}\right]$$

$$P(Y_1) = 0.0864$$
$$P(Y_2) = 0.0781$$
$$P(Y_3) = 0.0707$$

2-Lane Crossing – west side

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P\big(Y_j\big)\right]\left[\frac{\big(2P_b(1-P_b)M_y\big) + \ \big(P_b{}^2 M_y{}^2\big)}{P_d}\right]$$

$$P(Y_1) = 0.0852$$

Plug these into equation above to determine average pedestrian delay.

$$d_p = \sum_{i=1}^{3} 11.8(i-0.5)P\big(Y_{i)}\big) + [0.90 - \sum_{i=1}^{3} P(Y_i)] * 46 = 35.1\ sec$$

$$d_p = \sum_{i=1}^{1} 16.7(i - 0.5)P\big(Y_{i)}\big) + [0.63 - \sum_{i=1}^{1} P(Y_i)] * 9 = 5.7\ sec$$

$$40.8\ sec = LOS\ E$$

PM Peak Hour

Same process as AM Peak Hour:

$$Delay = \ 23.3\ sec = LOS\ D$$

Analysis of the crossing with a median indicates that the pedestrians crossing would experience LOS E during the AM and LOS D during the PM Peak Hour with a median. Pedestrian traffic is essentially equal in the AM and PM.

Result: Unacceptable Service Level in the AM peak hour, but acceptable in the PM peak hour with a median extended through the crossing location. No other changes are recommended.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location: Example 3: Four Lane Divided Street — Date:

City, State: Any City, Minnesota — Scenario: AM Peak Hour, Median

Reviewer(s): — Agency:

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☑	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	52	t_s =	3	L =	25	t_s =	3
S_p =	4.8	t_c =	13.8	S_p =	4.8	t_c =	8.21

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		t_c =	13.8	v_p =		t_c =	8.21
v =	0.17	N_c =		v =	0.12	N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c-1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	6	N_p =		W_c =	6	N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p-1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	13.8	$t_{c,G}$ =		t_c =	8.21	$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1-P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.8			$t_{c,G}$ =	8.21		
v =	0.17	P_b =	0.69	v =	0.12	P_b =	0.39
N =	2	P_d =	0.9	N =	2	P_d =	0.63

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

	crossing 1			crossing 2	
$t_{c,G}$ =	13.83		$t_{c,G}$ =	8.208	
v =	0.17	d_g = 42.067	v =	0.12	d_g = 5.7734

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

	crossing 1			crossing 2	
d_g =	42.07		d_g =	5.773	
P_d =	0.905	d_{gd} = 46.494	P_d =	0.627	d_{gd} = 9.2145

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

	crossing 1			crossing 2	
h =	11.8	n = 3	h =	16.67	n = 1
		d_p = 35.1			d_p = 5.7

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 17%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2 \qquad P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	40.8
LOS	E

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 3: Four Lane Divided Street	Date:	
City, State:	Any City, Minnesota	Scenario:	PM Peak Hour, Median
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☑ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☑ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	52	t_s =	3	L =	25	t_s =	3
S_p =	4.8	t_c =	13.8	S_p =	4.8	t_c =	8.21

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon)e^{(\upsilon_p - \upsilon)t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	13.8	υ_p =		t_c =	8.21
υ =	0.1	N_c =		υ =	0.16	N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c-1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	6	N_p =		W_c =	6	N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	13.8	$t_{c,G}$ =		t_c =	8.21	$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1-P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.8			$t_{c,G}$ =	8.21		
υ =	0.1	P_b =	0.5	υ =	0.16	P_b =	0.48
N =	2	P_d =	0.75	N =	2	P_d =	0.73

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}(e^{v t_{c,G}} - v t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.83			$t_{c,G}$ =	8.208		
v =	0.1	d_g =	16.048	v =	0.16	d_g =	8.7826

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	16.05			d_g =	8.783		
P_d =	0.749	d_{gd} =	21.419	P_d =	0.731	d_{gd} =	12.013

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	20.0	n =	1	h =	12.5	n =	1
		d_p =	15.0			d_p =	8.3

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 17%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

Summary	
Average	23.3
LOS	D

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Example 4: Four-Lane Undivided Urban Street Crossing

Site Review

Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is located along a signalized street. The crossing location is unmarked. Roadway is two lanes in each direction, parking along the street.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

LRRB

Location:	Example 4: Four Lane Undivided Urban Street	Date:	
City, State:		Scenario:	
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.
- Crossing 1: 60 ft.
- Crossing 2: ft.

Median: width of median at crossing location: ft.

Crossing Width: effective crosswalk width: 8 ft.

Raised Median Available?	☐ Yes	☑ No
ADA Compliant Median Available (minimum 4' x 4' landing)?	☐ Yes	☑ No
Curb Ramps Available?	☐ Yes	☑ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?	☐ Yes	☑ No

Speed: Posted or 85th percentile speed: 30 mph

Roadway Curvature and Sight Distances: Average walking speed: 5.7 ft/s

Is the crossing location within a horizontal or vertical curve? ☑ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	197 ft.	provided?	☑ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	597 ft.	provided?	☐ Yes	☑ No
Direction 2:	Pedestrian Sight Distance (PedSD)	ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts

	vehicles: Hourly	vehicles: Pk 15-min	pedestrians: Hourly	pedestrians: Pk 15-min
Daily		13,700		
AM Peak	1,183	329	34	11
PM Peak	1,111	294	43	14

Additional Site Characteristics

Lighting:
Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☑ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern?

Signing: Currently signed at crosswalk? ☐ Yes ☑ No

Currently signed in advance of crosswalk? ☐ Yes ☑ No

Distances? direction 1: ft. direction 2: ft.

Enhancements: What enhancements are currently at the crossing location?

Adjacent Facilities: Distance to nearest marked crosswalk? 220 ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? Traffic Signal

Distance to nearest all-way stop, roundabout or signalized intersection: 220 ft.

Could another location serve the same pedestrian crossing movement? ☑ Yes ☐ No

Could another location serve the the movement more effectively? ☑ Yes ☐ No

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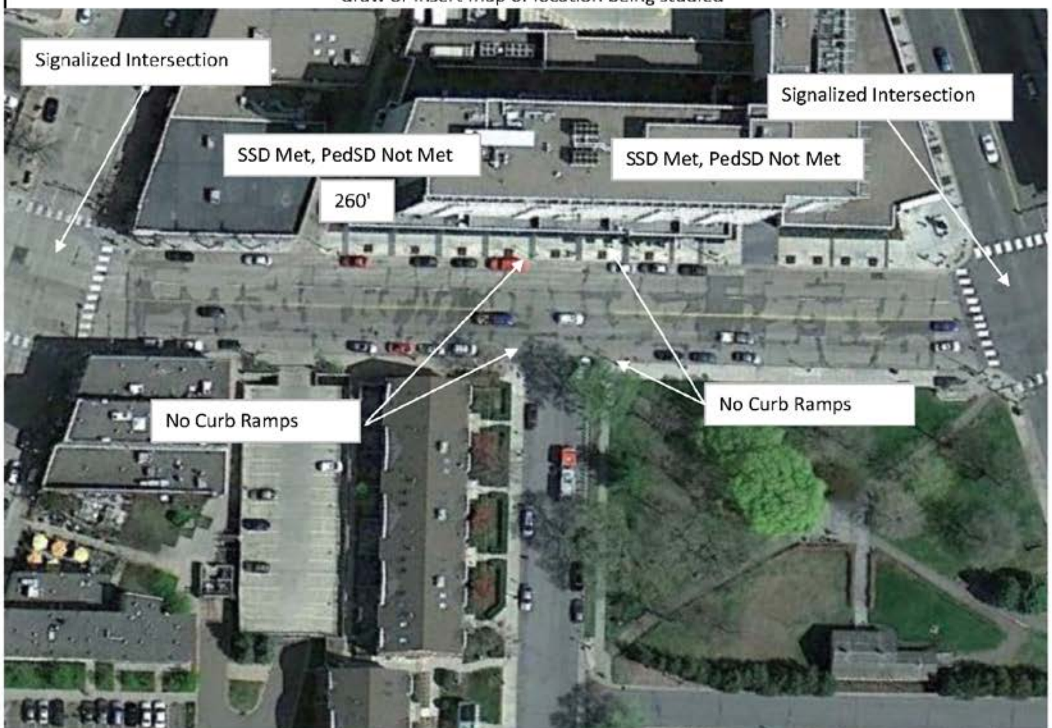
Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Parking on both sides of street. Signals one block in either direction.
Direct connections across at crossing location.
On a grade. Street is lower to west, higher to east.

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Safety Review

No pedestrian crashes at the location within last ten years. There have been three rear-end crashes at the location within the last ten years. Rear end crashes could be due to pedestrian yielding or the adjacent traffic signals. No conclusions are recognized from the crash data.

SSD, PedSD Calculation

$$SSD = d_{PRT} + d_{MT} = 1.47Vt + 1.075\frac{V^2}{a}$$

Where:

$\mathrm{d_{PRT}}$ = driver perception − reaction distance, (ft)

$\mathrm{d_{MT}}$ = braking distance (ft)

V = design speed (mph)

t = brake reaction time (s) [**DEFAULT = 2.5 sec**]

a = deceleration rate $(\frac{\mathrm{ft}}{\mathrm{s}^2})$ [**DEFAULT =** $\mathbf{11.2\ \frac{ft}{s^2}}$]

$$SSD = 1.47 * 30 * 2.5 + 1.075\frac{30^2}{11.2} = 196.6\ ft\ \approx 197\ ft$$

Looking at a map of the crossing, there is sufficient stopping sight distance for this crossing.

$$PedSD = 1.47V(\frac{L}{S_p} + t_s)$$

Where:

L = length of crossing (ft)

$\mathrm{S_p}$ = average pedestrian walking speed $\left(\frac{\mathrm{ft}}{\mathrm{s}}\right)$ [$\boldsymbol{DEFAULT = 3.5\frac{ft}{s}}$]

t_s = pedestrian start − up and clearance time (s) [**DEFAULT = 3.0 sec**]

$$PedSD = 1.47 * 30 * \left(\frac{60}{5.7} + 3.0\right) = 597\ ft$$

Again, looking at a map of the crossing, there is not a sufficient pedestrian sight distance for one direction. There is approximately 400 to 500 ft available to the east, and approximately 1,000 ft available to the west.

HCM Analysis

Determine inputs:

V = 1,183 in AM peak hour and 1,111 in PM peak hour

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	60
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5.7
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	1,183
Peak 15-minute volume (veh)				329
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8
N = number of through lanes crossed	N =	INT(L/11)	N =	4

AM Peak Hour

Step 1: Identify Two-Staged Crossings

There is no median. There are no curb ramps.

Step 2: Determine Critical Headway

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

$$t_c = \frac{60}{5.7} + 3 = 13.5\ sec$$

Pedestrian Platooning is observed, so the spatial distribution of pedestrians should be computed:

1. Use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

$$v_p = \frac{V_p}{PHF} = \frac{34}{\frac{34}{4 * 11}} = 44 \frac{ped}{hr} = 0.01\ ped/s$$

$$v = \frac{V}{PHF} = \frac{1183}{\frac{1183}{4*329}} = 1316\ veh/hr = 0.37 \text{ veh/s}$$

$$N_c = \frac{(0.01)e^{(0.012)(13.5)} + (0.37)e^{-(0.37)(13.5)}}{(0.01 + 0.37)e^{(0.01-0.37)(13.5)}} = 4.77\ peds$$

2. Compute Spatial Distribution:

$$N_p = Int\frac{8.0(N_c - 1)}{W_c} + 1$$

N_c = 5.32 peds (from above)
W_c = No crosswalk width – so use 8ft

$$N_p = Int\left[\frac{8.0(5.32 - 1)}{8}\right] + 1 = 4\ peds$$

3. Compute Group Critical Headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

t_c = 18.6 s
N_p = 29 peds (from above)

$$t_{c,G} = 13.5 + 2(4 - 1) = 19.5\ sec$$

Step 3: Estimate Probability of a delayed crossing

$$P_b = 1 - e^{\frac{-t_{c,G}v}{N}}$$

$$P_d = 1 - (1 - P_{b)}{}^N$$

N = 4 lanes

$$P_b = 1 - e^{\frac{-19.5(0.37)}{4}} = 0.84$$

$$P_d = 1 - (1 - 0.84)^4 = 0.9993$$

Step 4: Calculate Average Delay to Wait for Adequate Gap

$$d_g = \frac{1}{v}(e^{vt_{c,G}} - vt_{c,G} - 1)$$

$$d_{gd} = \frac{d_g}{P_d}$$

$$d_g = \frac{1}{0.37}\left(e^{0.37(19.5)} - 0.37(19.5) - 1\right) = 3{,}689\ sec$$

$$d_{gd} = \frac{3{,}689}{0.9993} = 3{,}691\ sec$$

In reality, as this is in a signalized corridor, the signals platoon traffic through the area.

Step 5: Estimate Delay Reduction due to Yielding Vehicles

There is no yield rate because the crosswalk is unmarked (M_y=0). Therefore, there is no reduction in delay due to yielding vehicles, and the average pedestrian delay is the same as in step 4.

$$d_p = d_{gd} = 3{,}691\ sec = LOS\ F$$

PM Peak Hour

Same process as AM Peak Hour:

$$Delay = 1{,}886\ sec = LOS\ F$$

Analysis of the crossing indicates that the crossing is experiencing LOS F during the AM and PM Peak Hours.

Result: Unacceptable Service Level in the AM and PM. **Go to Step 6 of the evaluation flowchart.**

<u>Review Origins and Destinations, Alternate Routes</u>

Origins and Destinations

The proposed crossing is located near a commercialized/shopping area. The crossing would connect a densely populated residential area to a shopping area.

Alternative Route Analysis

Calculate how much time it would take for a pedestrian to walk to the nearest adjacent marked crossing, cross the roadway, and return to the location where they started.

This total amount of time will be compared to the average pedestrian delay (average measured wait time).

Distance to nearest marked crossing = 220 ft (Signalized intersection)

Walking Time to Signalized Intersection:

$$\frac{220\ ft}{5.7\frac{ft}{s}} = 39\ sec$$

Wait Time and Crossing Time at Intersection:

Assume average wait time of 30 sec.

$$30 + \frac{65\ ft}{5.7\frac{ft}{s}} = 41\ sec$$

Walking Time to Original Location:

$$\frac{220\ ft}{5.69\frac{ft}{s}} = 39\ sec$$

Total Time:

$$39 + 41 + 39 = 119\ sec$$

Average Measured Wait Time (Pedestrian Delay) without a crossing

$$1{,}886\ to\ \ 3{,}691\ \text{sec with current crossing}\ \ (from\ HCM\ Analysis)$$

Because the alternative route time is considerably less than the average wait time, pedestrians should use the crossing at the signalized intersection to cross the roadway.

Result: There are acceptable alternative routes that pedestrians can use at this location. Since there is an acceptable alternative route at either of the adjacent signalized intersections, no changes are recommended at the crossing location studied.

Measures may be taken to prevent pedestrians from crossing, but knowledge of the area indicates that pedestrians will cross at the location no matter what the delay is.

If the signals were further away, a High Level Treatment of a Traffic Signal or Pedestrian Hybrid Beacon may be appropriate.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 4: Four Lane Undivided Urban Street	Date:	
City, State:		Scenario:	AM Peak Hour
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☐ Yes	☑ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	60	t_s =	3	L =		t_s =	
S_p =	5.7	t_c =	13.5	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =	0.01	t_c =	13.5	υ_p =		t_c =	
υ =	0.37	N_c =	4.77	υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =	4.77			N_c =			
W_c =	8	N_p =	4	W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	4			N_p =			
t_c =	13.5	$t_{c,G}$ =	19.5	t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19.5			$t_{c,G}$ =			
υ =	0.37	P_b =	0.84	υ =		P_b =	
N =	4	P_d =	1	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19.53			$t_{c,G}$ =			
v =	0.37	d_g =	3688.5	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	3689			d_g =			
P_d =	0.999	d_{gd} =	3691.2	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_{i=1}) = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_{i>1}) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	3691.2
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location:	Example 4: Four Lane Undivided Urban Street	Date:	
City, State:		Scenario:	PM Peak Hour
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing? ☐ Yes ☑ No

If yes, does the median refuge meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No

If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	60	t_s =	3	L =		t_s =	
S_p =	5.7	t_c =	13.5	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =	0.02	t_c =	13.5	v_p =		t_c =	
v =	0.33	N_c =	4.78	v =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =	4.78			N_c =			
W_c =	8	N_p =	4	W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	4			N_p =			
t_c =	13.5	$t_{c,G}$ =	19.5	t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19.5			$t_{c,G}$ =			
v =	0.33	P_b =	0.8	v =		P_b =	
N =	4	P_d =	1	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{\upsilon}\left(e^{\upsilon t_{c,G}} - \upsilon t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
υ = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19.53			$t_{c,G}$ =			
υ =	0.33	d_g =	1882.7	υ =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	1883			d_g =			
P_d =	0.998	d_{gd} =	1885.7	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/υ
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	1885.7
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Example 5: Four-Lane Divided Urban Highway Crossing

<u>Site Review</u>

Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is located on a four lane highway with medians. The median at the crossing doesn't have a pedestrian platform because the crossing is currently unmarked.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 5: Four Lane Undivided Highway	Date:	
City, State:		Scenario:	Noon Weekday Evaluation
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.
- Crossing 1: 52 ft.
- Crossing 2: 65 ft.

Median: width of median at crossing location: 10 ft.

Crossing Width: effective crosswalk width: 8 ft.

	Yes	No
Raised Median Available?	☑	☐
ADA Compliant Median Available (minimum 4' x 4' landing)?	☐	☑
Curb Ramps Available?	☑	☐
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?	☐	☑

Speed: Posted or 85th percentile speed: 45 mph

Roadway Curvature and Sight Distances: Average walking speed: 5.6 ft/s

Is the crossing location within a horizontal or vertical curve? ☐ Yes ☐ No

Equations to calculate the following are located on the next page

			provided? Yes	provided? No
Direction 1:	Stopping Sight Distance (SSD)	360 ft.	☑	☐
Direction 2:	Stopping Sight Distance (SSD)	360 ft.	☑	☐
Direction 1:	Pedestrian Sight Distance (PedSD)	813 ft.	☑	☐
Direction 2:	Pedestrian Sight Distance (PedSD)	966 ft.	☑	☐

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts

	vehicles: Hourly	vehicles: Pk 15-min	pedestrians: Hourly	pedestrians: Pk 15-min
Daily	11,200			
AM Peak				
PM Peak	698	237	2	2

(Vehicles Daily: 11,200; Pedestrians Daily: blank)

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☑ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern?

Signing: Currently signed at crosswalk? ☐ Yes ☑ No

Currently signed in advance of crosswalk? ☐ Yes ☑ No

Distances? direction 1 ___ ft. direction 2 ___ ft.

Enhancements: What enhancements are currently at the crossing location? Traffic Signal

Adjacent Facilities: Distance to nearest marked crosswalk? 1,000 ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk?

Distance to nearest all-way stop, roundabout or signalized intersection: 1,000 ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☑ No

Could another location serve the the movement more effectively? ☐ Yes ☑ No

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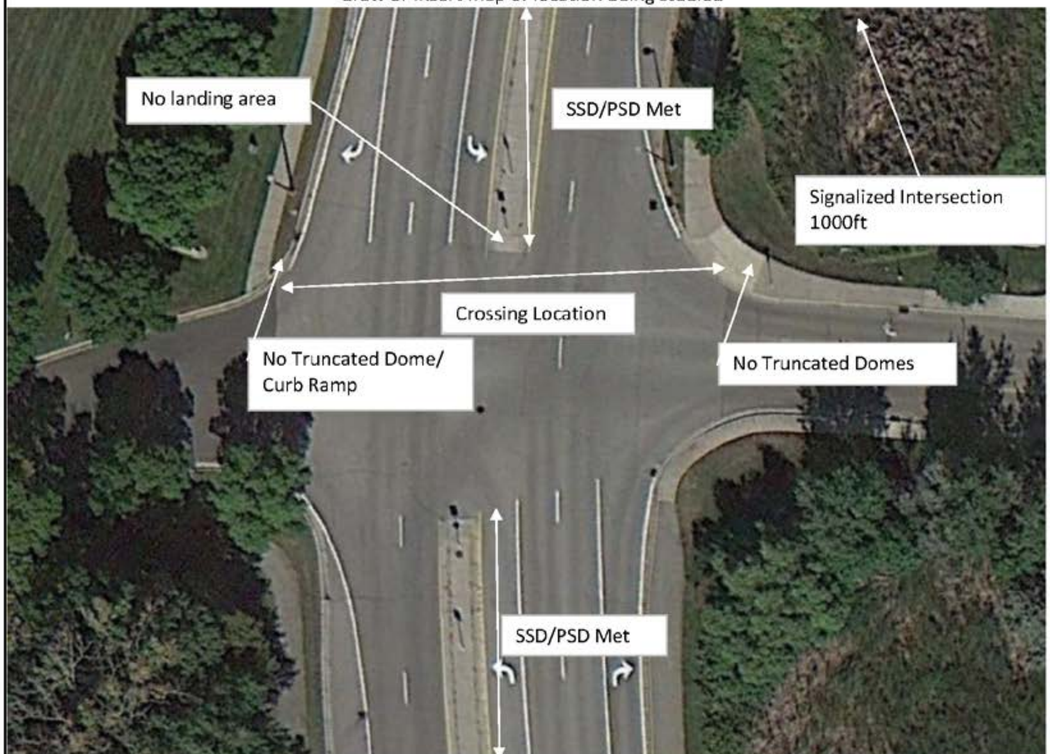
Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Crossing location currently unsigned and unmarked.
Median could be extended

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Page 2 of 2

Safety Review

No pedestrian crashes or rear-ends at the location within last ten years. Overall, there have been two crashes at this intersection over the last ten years. No conclusions made regarding crash data.

SSD, PedSD Calculation

$$SSD = 360\ ft$$
$$PedSD_{Total} = 1{,}700\ ft$$

The SSD is met for this crossing, but PedSD is not.

HCM Analysis

Midday Peak Hour

Yield Rate = 0% (Unmarked Crossing)

$$Delay = 3{,}026\ sec = LOS\ F$$

Result: Unacceptable Service Level, **go to Step 6 of the Evaluation Flowchart.**

Review Origins and Destinations, Alternate Routes

Origins and Destinations

The crossing connects the business parking lot to shopping/restaurant area. This crossing is a direct origin-destination connection because pedestrians would most likely not walk to the signalized intersection to the north to cross.

Alternative Route Analysis

Calculate how much time it would take for a pedestrian to walk to the nearest adjacent marked crossing, cross the roadway, and return to the location where they started.

This total amount of time will be compared to the average pedestrian delay (average measured wait time). The signalized intersection (1000 ft north of the crossing) will be used as the alternative route.

Total Time = 601 sec

Average Measured Wait Time (Pedestrian Delay)

$$3{,}026\ \text{sec}\ with\ current\ crossing\ (from\ HCM\ Analysis)$$

While the alternate route provides a faster time, it is still unacceptable, resulting in 10 minutes to travel the alternate route.

Result: There is not an acceptable alternative route near the crossing being studied and there is a direct origin-destination connection at the crossing. **Go to step 7 of the evaluation flowchart.**

Access Spacing and Functional Classification
The crossing is not located in a signalized corridor.

Speed and Pedestrian Use
The speed limit is 45 mph.

There were 2 pedestrians during the peak hour.

Result: Consider appropriate traffic calming treatments in conjunction with or without appropriate uncontrolled crossing treatments. **Go to appropriate Step 10 of evaluation flowchart.**

School Crossing
This is not a school crossing, **go to Step 9**.

FHWA Safety Guidance
Multi-lane with raised median, speed limit = 45 mph, ADT = 11,200. Results in N designation. **Go to Step 11, Do Nothing or High Level Treatments**.

Why do we go to this step if the median could be lengthened to reduce crossing distance?

Say the existing median is extended. As there is already a median along the roadway, it is anticipated that extension of the median would have little to no effect on motorist yielding. Repeat Step 4 of the Evaluation Flowchart.

Check PedSD with shorter crossing distances.

$$PedSD_{SB} = 813\ ft$$
$$PedSD_{NB} = 966\ ft$$

$$Delay = 238\ sec = LOS\ F$$

Result
Still Unacceptable Service Level.

The pedestrian volume is so low, that any additional treatments would likely not be cost effective. Additionally, the safety would likely be decreased, as consistent with FHWA study.

Do Nothing or High Level Treatment Options:
Based on the pedestrian counts, it is unlikely that any High Level Treatments would be justified. The vehicle counts in the area should be reviewed to determine if a signal could be justified based on the intersection turning movement counts. If not, the recommended option would be to do nothing, leave the crossing unmarked and unsigned.

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 5	Date:	
City, State:		Scenario:	
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1:

Evaluation Inputs:

Evaluation Inputs	defaults:		Input Table:	
L = crosswalk length (ft)			L =	127
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5.6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	698
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	0.00
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	0.26
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	4

*no platooning observed

Crossing 2:

(only used for two-stage crossings)

Evaluation Inputs:

Evaluation Inputs	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	3026.1
LOS	F

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location:	Example 5: Four Lane Divided Urban Highway	Date:	
City, State:		Scenario:	Noon Peak Hour, Weekday
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☑ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☑ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	127	t_s =	3	L =		t_s =	
S_p =	5.6	t_c =	25.7	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		t_c =	25.7	v_p =		t_c =	
v =	0.26	N_c =		v =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c-1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	25.7	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	25.7			$t_{c,G}$ =			
v =	0.26	P_b =	0.81	v =		P_b =	
N =	4	P_d =	1	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1			crossing 2		
$t_{c,G}$ =	25.68		$t_{c,G}$ =		
v =	0.26	d_g = 3022.3	v =		d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1			crossing 2		
d_g =	3022		d_g =		
P_d =	0.999	d_{gd} = 3026.1	P_d =		d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1			crossing 2		
h =		n =	h =		n =
		d_p =			d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	3026.1
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations
Intersection and Mid-Block Crossings

Crossing Location:	Example 5	Date:	
City, State:		Scenario:	Staged Crossing
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: East

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	52
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5.6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	349
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.26
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: West

(only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	65
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	349
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.26
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	237.6
LOS	F

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location:	Example 5: Four Lane Divided Urban Highway	Date:	
City, State:		Scenario:	Staged Crossing
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☑	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	52	t_s =	3	L =	65	t_s =	3
S_p =	5.6	t_c =	12.3	S_p =	5.6	t_c =	14.6

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	12.3	υ_p =		t_c =	14.6
υ =	0.26	N_c =		υ =	0.26	N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =	8	N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	12.3	$t_{c,G}$ =		t_c =	14.6	$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	12.3			$t_{c,G}$ =	14.6		
υ =	0.26	P_b =	0.8	υ =	0.26	P_b =	0.85
N =	2	P_d =	0.96	N =	2	P_d =	0.98

Calculations Sheet 1

Developed by Bolton Menk, Inc.
for the Local Road Research Board.

LRRB

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1		crossing 2	
$t_{c,G}$ = 12.29		$t_{c,G}$ = 14.61	
v = 0.26	d_g = 77.686	v = 0.26	d_g = 153.11

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1		crossing 2	
d_g = 77.69		d_g = 153.1	
P_d = 0.959	d_{gd} = 81.007	P_d = 0.978	d_{gd} = 156.62

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1		crossing 2	
h =	n =	h =	n =
	d_p =		d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	237.6
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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Example 6: Four-Lane Divided Urban High Pedestrian Use Crossing

Site Review

Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is located is on a four lane roadway with medians. The median at the crossing doesn't have a pedestrian platform and is currently not extended to the crosswalk. **There are two flashing beacons at the crossing along with pavement markings and signs.**

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 6	Date:	
City, State:		Scenario:	Noon Weekday
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.	Crossing 1	118	ft.			
	Crossing 2		ft.			
Median: width of median at crossing location			ft.			
Crossing Width: effective crosswalk width		6	ft.			
Raised Median Available?				☑ Yes	☐ No	
ADA Compliant Median Available (minimum 4' x 4' landing)?				☐ Yes	☑ No	
Curb Ramps Available?				☑ Yes	☐ No	
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?				☐ Yes	☑ No	
Speed:	Posted or 85th percentile speed	40	mph			
Roadway Curvature and Sight Distances:	Average walking speed	5.6	ft/s			
Is the crossing location within a horizontal or vertical curve?				☐ Yes	☐ No	
Equations to calculate the following are located on the next page						
Direction 1: Stopping Sight Distance (SSD)	301	ft.	provided?	☑ Yes	☐ No	
Direction 2: Stopping Sight Distance (SSD)		ft.	provided?	☑ Yes	☐ No	
Direction 1: Pedestrian Sight Distance (PedSD)	1415	ft.	provided?	☑ Yes	☐ No	
Direction 2: Pedestrian Sight Distance (PedSD)		ft.	provided?	☑ Yes	☐ No	

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	**vehicles:**		Daily	8,900	**pedestrians:**		Daily	
AM Peak	Hourly		Pk 15-min		Hourly		Pk 15-min	
PM Peak	Hourly	632	Pk 15-min	252	Hourly	29	Pk 15-min	16

Additional Site Characteristics

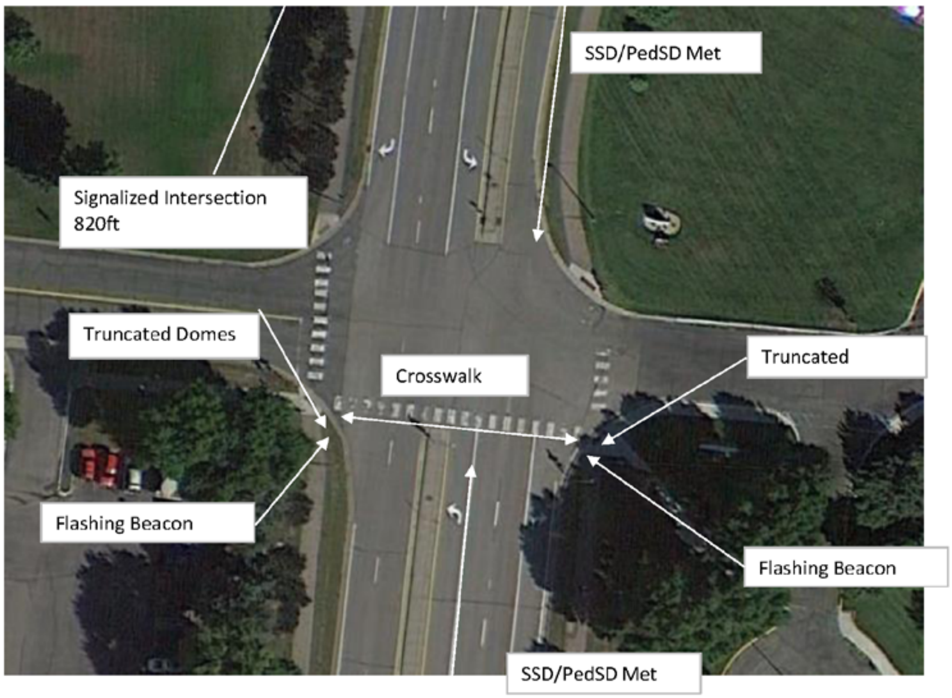
Lighting:				
Is street lighting present and does it light the crosswalk location?			☑ Yes	☐ No
Crosswalk Pavement Markings: Is the pedestrian crossing currently marked?			☐ Yes	☐ No
What is the condition of the markings?	☐ Excellent	☑ Good	☐ Fair	☐ Poor
Are the markings easily defined?			☑ Yes	☐ No
Do they need replacement?			☐ Yes	☑ No
What is the crosswalk marking pattern?	Continental			
Signing: Currently signed at crosswalk?			☑ Yes	☐ No
Currently signed in advance of crosswalk?			☑ Yes	☐ No
Distances?	direction 1: 475 ft.	direction 2: 498 ft.		
Enhancements: What enhancements are currently at the crossing location?	Pedestrian Flasher System, Side Mounted			
Adjacent Facilities: Distance to nearest marked crosswalk?	820 ft.			
What pedestrian control devices are present at the nearest adjacent marked crosswalk?	Traffic Signal			
Distance to nearest all-way stop, roundabout or signalized intersection	820 ft.			
Could another location serve the same pedestrian crossing movement?			☐ Yes	☑ No
Could another location serve the the movement more effectively?			☐ Yes	☑ No

Page 1 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Crossing currently signed and marked. Flashing beacons pedestrian actuated.
Crossing updated as compared to aerial with flashers, updated markings, and median cut-through.

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Page 2 of 2

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 6	Date:	
City, State:		Scenario:	Noon Weekday, Staged Crossing
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.
- Crossing 1: 50 ft.
- Crossing 2: 60 ft.

Median: width of median at crossing location: 8 ft.

Crossing Width: effective crosswalk width: 6 ft.

Raised Median Available?	☑ Yes	☐ No
ADA Compliant Median Available (minimum 4' x 4' landing)?	☐ Yes	☑ No
Curb Ramps Available?	☑ Yes	☐ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?	☐ Yes	☑ No

Speed: Posted or 85th percentile speed: 40 mph

Roadway Curvature and Sight Distances: Average walking speed: 5.6 ft/s

Is the crossing location within a horizontal or vertical curve? ☐ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1: Stopping Sight Distance (SSD)	301 ft.	provided?	☑ Yes	☐ No
Direction 2: Stopping Sight Distance (SSD)	301 ft.	provided?	☑ Yes	☐ No
Direction 1: Pedestrian Sight Distance (PedSD)	701 ft.	provided?	☑ Yes	☐ No
Direction 2: Pedestrian Sight Distance (PedSD)	806 ft.	provided?	☑ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:		Daily	8,900	pedestrians:		Daily	
AM Peak	Hourly		Pk 15-min		Hourly		Pk 15-min	
PM Peak	Hourly	632	Pk 15-min	252	Hourly	29	Pk 15-min	16

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☐ No

What is the condition of the markings? ☐ Excellent ☑ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☑ Yes ☐ No

Do they need replacement? ☐ Yes ☑ No

What is the crosswalk marking pattern? Continental

Signing: Currently signed at crosswalk? ☑ Yes ☐ No

Currently signed in advance of crosswalk? ☑ Yes ☐ No

Distances? direction 1: 475 ft. direction 2: 498 ft.

Enhancements: What enhancements are currently at the crossing location? Pedestrian Flasher System, Side Mounted

Adjacent Facilities: Distance to nearest marked crosswalk? 820 ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? Traffic Signal

Distance to nearest all-way stop, roundabout or signalized intersection: 820 ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☑ No

Could another location serve the the movement more effectively? ☐ Yes ☑ No

Safety Review
No pedestrian crashes at the location within last ten years. There were five rear-end crashes and 22 crashes over the last ten years. Motorists may not be seeing the pedestrians until too late. The pedestrian crossing flashers were recently installed so data may indicate need before flashers were installed.

SSD, PedSD Calculation

$$SSD = 301\ ft$$
$$PedSD_{Unstaged} = 1{,}415\ ft$$
$$PedSD_{SB} = 701\ ft$$
$$PedSD_{NB} = 806\ ft$$

The SSD is met for this crossing. PedSD is not, unless it becomes a staged crossing.

HCM Analysis
No yielding rate available for pedestal mounted flashing beacons on a multi-lane highway, but there is likely some yielding. For purposes of this analysis, it is estimated to be 25%, one half the yield rate of overhead beacons.

Midday Peak Hour

Yield Rate = 25% (Flashing Beacons)

$$Delay => 10000\ sec = LOS\ F$$

Result: Unacceptable Service Level, **go to step 6 of the evaluation flowchart.**

Review Origins and Destinations, Alternate Routes
Alternative routing not considered since it is important enough based on the presence of pedestrian flasher system that was just recently installed.

Go to step 7 of the evaluation flowchart.

Access Spacing and Functional Classification
The crossing is not located in a signalized corridor.

Speed and Pedestrian Use
The speed limit is 40 mph.

There were 29 pedestrians during the peak hour.

Go to appropriate Step 9 of evaluation flowchart.

FHWA Safety Guidance
Vehicle ADT < 9,000

Roadway Type: Multilane with raised median
Speed: 40 mph
Result: P, Marked Crosswalks alone are insufficient

Go to Appropriate Step 11 of evaluation flowchart.

Traffic Calming Treatment Options

Based on the FHWA Safety Guidance, the median is likely to produce some improvement by shortening the crossing distance and bring it into the P designation versus N designation as far as safety is concerned. The existing median could be extended. As there is already a median along the roadway, it is anticipated that extension of the median would have little to no effect on motorist yielding. Additionally, due to the multi-lane facility, overhead beacons could provide additional benefit.

Repeat Step 4 of the Evaluation Flowchart.

$$Delay = 57\ sec = LOS\ F$$

Result: Unacceptable Service Level. Still LOS F, but delay reduced substantially.

An option would be to replace the beacons with RRFBs if you are already thinking of installing overhead beacons.

Repeat Step 4 of the Evaluation Flowchart.

$$Delay = 13\ sec = LOS\ C$$

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 6	Date:	
City, State:		Scenario:	Unstaged Crossing
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: South Side

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	118
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5.6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	632
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.18
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.280
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	4

*no platooning observed

Crossing 2: (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	25%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	#########
LOS	F

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location:	Example 6	Date:	
City, State:		Scenario:	
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☑	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	118	t_s =	3	L =		t_s =	
S_p =	5.6	t_c =	24.1	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =	0.18	t_c =	24.1	υ_p =		t_c =	
υ =	0.28	N_c =	331	υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c-1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =	331			N_c =			
W_c =	6	N_p =	440	W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	440			N_p =			
t_c =	24.1	$t_{c,G}$ =	902	t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	902			$t_{c,G}$ =			
υ =	0.28	P_b =	1	υ =		P_b =	
N =	4	P_d =	1	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}(e^{v t_{c,G}} - v t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	902.1			$t_{c,G}$ =			
v =	0.28	d_g =	2E+110	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	#####			d_g =			
P_d =	1	d_{gd} =	2E+110	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	14.3	n =	1E+109	h =	#####	n =	######
		d_p =	######			d_p =	######

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 25%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

Summary	
Average	#########
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 6	Date:	
City, State:		Scenario:	Staged Crossing, Overhead Beacons
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: West

Evaluation Inputs:

Evaluation Inputs	defaults:	Input Table:
L = crosswalk length (ft)		L = 50
S_p = average pedestrian walking speed (ft/s)	S_p = 3.5	S_p = 5.6
t_s = pedestrian start-up and end clearance time (s)	t_s = 3.0	t_s = 3
V = vehicular hourly volume (veh/hr)		V = 316
v_p = pedestrian flow rate (ped/s)	v_p = 0*	v_p = 0.18
v = vehicular flow rate (veh/s) = V/3600	v = V/3600	v = 0.280
W_c = crosswalk width (ft)	W_c = 8.0	W_c = 6.0
N = number of through lanes crossed (Integer)	N = INT(L/11)	N = 2

*no platooning observed

Crossing 2: East

(only used for two-stage crossings)

Evaluation Inputs:

Evaluation Inputs	defaults:	Input Table:
L = crosswalk length (ft)		L = 60
S_p = average pedestrian walking speed (ft/s)	S_p = 3.5	S_p = 6
t_s = pedestrian start-up and end clearance time (s)	t_s = 3.0	t_s = 3
V = vehicular hourly volume (veh/hr)		V = 316
v_p = pedestrian flow rate (ped/s)	v_p = 0*	v_p = 0.18
v = vehicular flow rate (veh/s) = V/3600	v = V/3600	v = 0.28
W_c = crosswalk width (ft)	W_c = 8.0	W_c = 6.0
N = number of through lanes crossed (Integer)	N = INT(L/11)	N = 2

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:
M_y = motorist yield rate (decimal)	M_y = 47%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	57.2
LOS	F

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Crossing Location:	Example 6	Date:	
City, State:		Scenario:	Staged Crossing with Overhead Beacons
Reviewer(s):		Agency:	

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☑	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	50	t_s =	3	L =	60	t_s =	3
S_p =	5.6	t_c =	11.9	S_p =	5.6	t_c =	13.7

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =	0.18	t_c =	11.9	v_p =	0.18	t_c =	13.7
v =	0.28	N_c =	11.1	v =	0.28	N_c =	18.3

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =	11.1			N_c =	18.3		
W_c =	6	N_p =	14	W_c =	6	N_p =	24

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	14			N_p =	24		
t_c =	11.9	$t_{c,G}$ =	37.9	t_c =	13.7	$t_{c,G}$ =	59.7

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	37.9			$t_{c,G}$ =	59.7		
v =	0.28	P_b =	1	v =	0.28	P_b =	1
N =	2	P_d =	1	N =	2	P_d =	1

Developed by Bolton Menk, Inc.
for the Local Road Research Board.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

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Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

	crossing 1			crossing 2	
$t_{c,G}$ =	37.93		$t_{c,G}$ =	59.71	
v =	0.28	d_g = 146193	v =	0.28	d_g = 7E+07

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

	crossing 1			crossing 2	
d_g =	1E+05		d_g =	7E+07	
P_d =	1	d_{gd} = 146196	P_d =	1	d_{gd} = 7E+07

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

	crossing 1			crossing 2	
h =	7.1	n = 20467	h =	7.143	n = 9E+06
		d_p = 28.4			d_p = 28.7

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 47%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	57.2
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 6	Date:	
City, State:		Scenario:	Staged Crossing, Overhead RRFBs
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: West

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	50
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5.6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	316
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.18
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.280
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: East

(only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	60
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	6
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	316
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.18
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.28
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	84%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	13.1
LOS	C

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

LRRB

Crossing Location: Example 6 | Date:
City, State: | Scenario: Staged Crossing with Overhead RRFBs
Reviewer(s): | Agency:

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☑	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☑
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☑	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	50	t_s =	3	L =	60	t_s =	3
S_p =	5.6	t_c =	11.9	S_p =	5.6	t_c =	13.7

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =	0.18	t_c =	11.9	υ_p =	0.18	t_c =	13.7
υ =	0.28	N_c =	11.1	υ =	0.28	N_c =	18.3

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =	11.1			N_c =	18.3		
W_c =	6	N_p =	14	W_c =	6	N_p =	24

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	14			N_p =	24		
t_c =	11.9	$t_{c,G}$ =	37.9	t_c =	13.7	$t_{c,G}$ =	59.7

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	37.9			$t_{c,G}$ =	59.7		
υ =	0.28	P_b =	1	υ =	0.28	P_b =	1
N =	2	P_d =	1	N =	2	P_d =	1

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for the Local Road Research Board.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{\upsilon}\left(e^{\upsilon t_{c,G}} - \upsilon t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
υ = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	37.93			$t_{c,G}$ =	59.71		
υ =	0.28	d_g =	146193	υ =	0.28	d_g =	7E+07

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	1E+05			d_g =	7E+07		
P_d =	1	d_{gd} =	146196	P_d =	1	d_{gd} =	7E+07

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/υ
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	7.1	n =	20467	h =	7.143	n =	9E+06
		d_p =	6.5			d_p =	6.6

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 84%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	13.1
LOS	C

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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Example 7: School Crossing

Site Review

Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is marked and signed as a school crossing with an in-road crossing sign. There are crossing guards during the times children travel to and from school.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location:	Example 7	Date:	
City, State:		Scenario:	School Crossing
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.	Crossing 1	40	ft.		
	Crossing 2		ft.		
Median: width of median at crossing location			ft.		
Crossing Width: effective crosswalk width		6	ft.		
Raised Median Available?				☐ Yes	☑ No
ADA Compliant Median Available (minimum 4' x 4' landing)?				☐ Yes	☐ No
Curb Ramps Available?				☐ Yes	☑ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?				☐ Yes	☐ No
Speed:	Posted or 85th percentile speed	30	mph		
Roadway Curvature and Sight Distances:	Average walking speed	4.3	ft/s		
Is the crossing location within a horizontal or vertical curve?				☐ Yes	☑ No

Equations to calculate the following are located on the next page

Direction 1: Stopping Sight Distance (SSD)	197	ft.	provided?	☑ Yes	☐ No
Direction 2: Stopping Sight Distance (SSD)		ft.	provided?	☐ Yes	☐ No
Direction 1: Pedestrian Sight Distance (PedSD)	543	ft.	provided?	☑ Yes	☐ No
Direction 2: Pedestrian Sight Distance (PedSD)		ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	vehicles:		Daily	5,600	pedestrians:	Daily	
AM Peak	Hourly	496	Pk 15-min	181	Hourly 9	Pk 15-min	5
PM Peak	Hourly	521	Pk 15-min	166	Hourly 6	Pk 15-min	4

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☑ Yes ☐ No

What is the condition of the markings? ☐ Excellent ☑ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☑ Yes ☐ No

Do they need replacement? ☐ Yes ☑ No

What is the crosswalk marking pattern? Continental

Signing: Currently signed at crosswalk? ☑ Yes ☐ No

Currently signed in advance of crosswalk? ☐ Yes ☑ No

Distances? direction 1 ____ ft. direction 2 ____ ft.

Enhancements: What enhancements are currently at the crossing location? high visibility markings, in-street signs school crossing guards

Adjacent Facilities: Distance to nearest marked crosswalk? ____ ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk?

Distance to nearest all-way stop, roundabout or signalized intersection 2000 ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☑ No

Could another location serve the the movement more effectively? ☐ Yes ☑ No

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied

Notes: No Ped Ramps
In Street School Crosing signs and crossing guards.

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Safety Review
No pedestrian crashes at the location within last ten years. There were a total of 3 crashes at this location over the last ten years, all being rear-end. Likely the result of yielding to pedestrians.

SSD, PedSD Calculation

$$SSD = 197\ ft$$
$$PedSD = 543\ ft$$

The SSD and PedSD is met for this crossing.

HCM Analysis
Since the crossing is primarily used by school children, walking speed changed to 3.5 ft/s in calculations of LOS.

AM Peak Hour

Yield Rate = 86% (Crossing Guards)

$$Delay = 7.3\ sec = LOS\ B$$

PM Peak Hour

Yield Rate = 86% (Crossing Guards)

$$Delay = 7.9\ sec = LOS\ B$$

Result
Acceptable Level of Service

Consider no changes to the existing crossing as far as treatments. Because there are crossing guards at the school crossings before and after school, the yield rates and safety are greatly improved.

One consideration is the addition of pedestrian curb ramps and truncated domes to make the crossing usable by all.

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 7	Date:	
City, State:		Scenario:	School Crossing, AM
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: __________

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	40
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	3.5
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	496
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.01
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.200
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: __________ (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	86%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	7.3
LOS	B

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location: ________________ Date: ________________

City, State: ________________ Scenario: ________________

Reviewer(s): ________________ Agency: ________________

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☐	☐
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐	☐
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐	☐

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	40	t_s =	3	L =		t_s =	
S_p =	3.5	t_c =	14.4	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =	0.01	t_c =	14.4	υ_p =		t_c =	
υ =	0.2	N_c =	1.41	υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =	1.41			N_c =			
W_c =	6	N_p =	1	W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	1			N_p =			
t_c =	14.4	$t_{c,G}$ =	14.4	t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	14.4			$t_{c,G}$ =			
υ =	0.2	P_b =	0.76	υ =		P_b =	
N =	2	P_d =	0.94	N =		P_d =	

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Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}(e^{v t_{c,G}} - v t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	14.43			$t_{c,G}$ =			
v =	0.2	d_g =	70.153	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	70.15			d_g =			
P_d =	0.944	d_{gd} =	74.3	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j
M_y = motorist yield rate (decimal) M_y = 86%

crossing 1				crossing 2			
h =	10.0	n =	7	h =	#####	n =	######
		d_p =	7.3			d_p =	######

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

Summary	
Average	7.3
LOS	B

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 7	Date:	
City, State:		Scenario:	School Crossing, PM
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: ____________________

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	40
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	3.5
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	521
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.180
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	6.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: ____________________ (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	86%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	7.9
LOS	B

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location: ______________________ Date: ______________

City, State: ______________________ Scenario: ______________

Reviewer(s): ______________________ Agency: ______________

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing? ☐ Yes ☐ No

If yes, does the median refuge meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No

If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	40	t_s =	3	L =		t_s =	
S_p =	3.5	t_c =	14.4	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =	0	t_c =	14.4	v_p =		t_c =	
v =	0.18	N_c =	1.22	v =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =	1.22			N_c =			
W_c =	6	N_p =	1	W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =	1			N_p =			
t_c =	14.4	$t_{c,G}$ =	14.4	t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G} v / N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	14.4			$t_{c,G}$ =			
v =	0.18	P_b =	0.73	v =		P_b =	
N =	2	P_d =	0.93	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	14.43			$t_{c,G}$ =			
v =	0.18	d_g =	54.601	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	54.6			d_g =			
P_d =	0.926	d_{gd} =	58.995	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	11.1	n =	5	h =	#####	n =	######
		d_p =	7.9			d_p =	######

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 86%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	7.9
LOS	B

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Example 8: Recreational Fields Crossing

Site Review

Conduct a field review and take pedestrian/vehicle counts during the peak hours.

The crossing location is on a four lane roadway with no medians. The studies crossing connects two schools and recreational facilities to a residential area.

Complete Field Review Worksheet.

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

LRRB

Location:	Example 8	Date:	
City, State:		Scenario:	
Reviewer(s):		Agency:	
Project #:		ID #:	

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.	Crossing 1	75	ft.
	Crossing 2		ft.
Median: width of median at crossing location		0	ft.
Crossing Width: effective crosswalk width		8	ft.
Raised Median Available?		☐ Yes	☑ No
ADA Compliant Median Available (minimum 4' x 4' landing)?		☐ Yes	☑ No
Curb Ramps Available?		☐ Yes	☑ No
ADA Compliant Curb Ramp Available (width, grades, truncated domes)?		☐ Yes	☑ No
Speed:	Posted or 85th percentile speed	35	mph
Roadway Curvature and Sight Distances:	Average walking speed	4.7	ft/s
Is the crossing location within a horizontal or vertical curve?		☐ Yes	☑ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	246 ft.	provided?	☑ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	975 ft.	provided?	☑ Yes	☐ No
Direction 2:	Pedestrian Sight Distance (PedSD)	ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	**vehicles:**		Daily	8,400	**pedestrians:**		Daily	
AM Peak	Hourly	402	Pk 15-min	140	Hourly	3	Pk 15-min	2
PM Peak	Hourly	585	Pk 15-min	180	Hourly	4	Pk 15-min	3

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☑ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☑ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern?

Signing: Currently signed at crosswalk? ☐ Yes ☑ No

Currently signed in advance of crosswalk? ☐ Yes ☑ No

Distances? direction 1 ft. direction 2 ft.

Enhancements: What enhancements are currently at the crossing location?

Adjacent Facilities: Distance to nearest marked crosswalk? 3,250 ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? Traffic Signal

Distance to nearest all-way stop, roundabout or signalized intersection 3,250 ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☑ No

Could another location serve the the movement more effectively? ☐ Yes ☑ No

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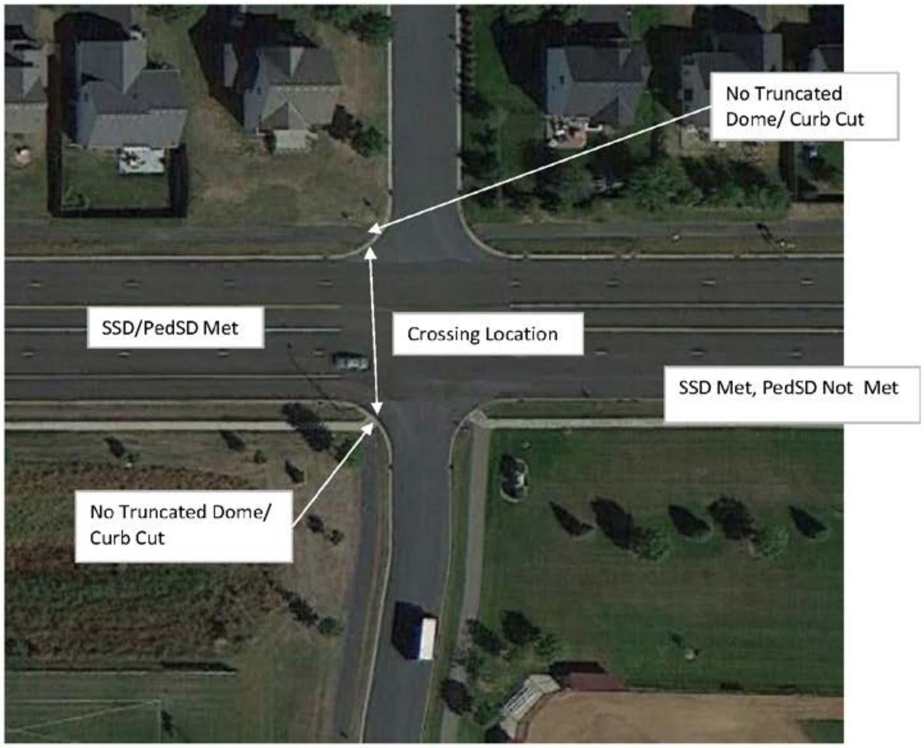
Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied



Notes: Crossing location currently unmarked and unsigned.
No ped

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph
L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Page 2 of 2

Safety Review

No pedestrian crashes at the location within last ten years. There was one rear-end crash and 5 crashes over the last ten years. No concerns as related to the pedestrian crossing.

SSD, PedSD Calculation

$$SSD = 246\ ft$$
$$PedSD = 975\ ft$$

The SSD and PedSD are met for this crossing.

HCM Analysis

AM Peak Hour

Yield Rate = 0%

$$Delay = 110\ sec = LOS\ F$$

PM Peak Hour

Yield Rate = 0%

$$Delay = 202\ sec = LOS\ F$$

Review Origins and Destinations, Alternative Routes

Origins and Destinations

The crossing connects a residential area to a school and trails (direct origin-destination). There is no marked crossing near the studied crossing, so pedestrians must choose the best place to cross.

Alternative Route Analysis

Calculate how much time it would take for a pedestrian to walk to the nearest adjacent marked crossing, cross the roadway, and return to the location where they started.

This total amount of time will be compared to the average pedestrian delay (average measured wait time). The nearest marked crossing is located 3,200 ft west of the unmarked crossing.

Because this crossing is so far away, it can be assumed that pedestrians will opt to wait at the unmarked crossing to cross the roadway.

Access Spacing and Functional Classification

The crossing is not located in a coordinated signalized corridor.

Speed and Pedestrian Use

The speed limit is 35 mph and the population is greater than 10,000.

There were 3 pedestrians during the AM peak hour and 4 pedestrians in the PM peak hour.

Result: **Go to Step 10**.

School Crossing

This is a crossing adjacent to two school and could be considered a school crossing if there are students that use the crossing, **go to Step 11, Traffic Calming Treatment Options**. Students were not observed using the crossing during the data collection period.

If it is not a school crossing, go to FHWA Safety Guidance. ADT = 8,200, Multilane without raised median, 35 mph. Results in P designation, **go to Step 11, Traffic Calming Treatment Options**.

Traffic Calming Treatment Options

Based on the existing options, a median with a refuge island or RRFB system with a median could be considered, but the cost to implement may be unreasonable based on the current pedestrian use. Overall, the crossing should likely be left alone.

School crossing guards could also be considered if there are children crossing the street before and after school hours. In which case, the crossing would be signed and marked as a school crossing, but a median with or without RRFB would also be recommended.

A median with a refuge island could decrease delay to 19.7 sec (LOS C) in the AM peak hour and 23.9 sec (LOS D) in the PM peak hour.

A median with a refuge island and an RRFB system could decrease delay to 14.8 sec (LOS C) in the AM peak hour and 14.5 sec (LOS C) in the PM peak hour.

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 8	Date:	
City, State:		Scenario:	AM Peak Hour
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1:

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	75
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.7
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	402
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.160
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	4

*no platooning observed

Crossing 2:

(only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	109.9
LOS	F

LRRB

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Crossing Location: ____________________ Date: ____________________

City, State: ____________________ Scenario: ____________________

Reviewer(s): ____________________ Agency: ____________________

Step 1: Identify Two-Stage Crossings

Question		
Is there a median available for a two-stage crossing?	☐ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	75	t_s =	3	L =		t_s =	
S_p =	4.7	t_c =	19	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	19	υ_p =		t_c =	
υ =	0.16	N_c =		υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	19	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19			$t_{c,G}$ =			
υ =	0.16	P_b =	0.53	υ =		P_b =	
N =	4	P_d =	0.95	N =		P_d =	

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Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1			crossing 2		
$t_{c,G}$ =	18.96		$t_{c,G}$ =		
v =	0.16	d_g = 104.56	v =		d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1			crossing 2		
d_g =	104.6		d_g =		
P_d =	0.952	d_{gd} = 109.85	P_d =		d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1			crossing 2		
h =		n =	h =		n =
		d_p =			d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1) = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2 \quad (i=1)$$

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right] \quad (i>1)$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	109.9
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 8	Date:	
City, State:		Scenario:	PM Peak Hour
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1:

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	75
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.7
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	585
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.200
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	4

*no platooning observed

Crossing 2:

(only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	202.2
LOS	F

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location: ____ Date: ____
City, State: ____ Scenario: ____
Reviewer(s): ____ Agency: ____

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☐ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	75	t_s =	3	L =		t_s =	
S_p =	4.7	t_c =	19	S_p =		t_c =	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	19	υ_p =		t_c =	
υ =	0.2	N_c =		υ =		N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ____ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =		N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	19	$t_{c,G}$ =		t_c =		$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	19			$t_{c,G}$ =			
υ =	0.2	P_b =	0.61	υ =		P_b =	
N =	4	P_d =	0.98	N =		P_d =	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	18.96			$t_{c,G}$ =			
v =	0.2	d_g =	197.65	v =		d_g =	

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	197.7			d_g =			
P_d =	0.977	d_{gd} =	202.22	P_d =		d_{gd} =	

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =		n =		h =		n =	
		d_p =				d_p =	

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	202.2
LOS	F

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Developed by Bolton Menk, Inc.
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2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 8	Date:	
City, State:		Scenario:	AM Peak Hour, Staged, RRFB
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: south

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	50
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.7
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	201
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	0.00
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	0.060
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: north

(only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	25
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	201
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	0.00
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	0.060
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	84%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	14.8
LOS	C

Uncontrolled Pedestrian Crossing Level of Service
Evaluation Worksheet

Crossing Location: ______________________ Date: ______________________
City, State: ______________________ Scenario: ______________________
Reviewer(s): ______________________ Agency: ______________________

Step 1: Identify Two-Stage Crossings

	Yes	No
Is there a median available for a two-stage crossing?	☐ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	50	t_s =	3	L =	25	t_s =	3
S_p =	4.7	t_c =	13.6	S_p =	4.7	t_c =	8.32

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	13.6	υ_p =		t_c =	8.32
υ =	0.06	N_c =		υ =	0.06	N_c =	

2. compute spatial distribution:

$$N_p = \text{Int}\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)
clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =	8	N_p =	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	13.6	$t_{c,G}$ =		t_c =	8.32	$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.6			$t_{c,G}$ =	8.32		
υ =	0.06	P_b =	0.34	υ =	0.06	P_b =	0.22
N =	2	P_d =	0.56	N =	2	P_d =	0.39

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{v t_{c,G}} - v t_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.64			$t_{c,G}$ =	8.319		
v =	0.06	d_g =	7.4723	v =	0.06	d_g =	2.4695

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	7.472			d_g =	2.469		
P_d =	0.559	d_{gd} =	13.372	P_d =	0.393	d_{gd} =	6.2845

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right)d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	33.3	n =	1	h =	33.33	n =	1
		d_p =	9.0			d_p =	5.8

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y = 84%

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] * \left[\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}\right]$$

Summary	
Average	14.8
LOS	C

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	Example 8	Date:	
City, State:		Scenario:	PM, Staged, RRFB
Reviewer(s):		Agency:	
Project Number:		ID #:	

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: south

Evaluation Inputs:

Evaluation Inputs	defaults:		Input Table:	
L = crosswalk length (ft)			L =	50
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	4.7
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	292
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.080
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing 2: north

(only used for two-stage crossings)

Evaluation Inputs:

Evaluation Inputs	defaults:		Input Table:	
L = crosswalk length (ft)			L =	25
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	5
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	3
V = vehicular hourly volume (veh/hr)			V =	293
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	0.00
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	0.080
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	8.0
N = number of lanes crossed (Integer)	N =	INT(L/11)	N =	2

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	84%

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay	14.5
LOS	C

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location: ______________________ Date: ______________________

City, State: ______________________ Scenario: ______________________

Reviewer(s): ______________________ Agency: ______________________

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing?	☐ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, does the median refuge need to meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)
S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =	50	t_s =	3	L =	25	t_s =	3
S_p =	4.7	t_c =	13.6	S_p =	4.7	t_c =	8.32

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{\upsilon_p e^{\upsilon_p t_c} + \upsilon e^{-\upsilon t_c}}{(\upsilon_p + \upsilon) e^{(\upsilon_p - \upsilon) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
υ_p = pedestrian flow rate (ped/s)
υ = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
υ_p =		t_c =	13.6	υ_p =		t_c =	8.32
υ =	0.08	N_c =		υ =	0.08	N_c =	

2. compute spatial distribution:

$$N_p = Int\left[\frac{8.0(N_c - 1)}{W_c}\right] + 1$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)

crossing 1				crossing 2			
N_c =				N_c =			
W_c =	8	N_p =		W_c =	8	N_p =	

clear width, if other than 8: ______ ft.

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				N_p =			
t_c =	13.6	$t_{c,G}$ =		t_c =	8.32	$t_{c,G}$ =	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{-t_{c,G}\upsilon/N}$$

$$P_d = 1 - (1 - P_b)^N$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
υ = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.6			$t_{c,G}$ =	8.32		
υ =	0.08	P_b =	0.42	υ =	0.08	P_b =	0.28
N =	2	P_d =	0.66	N =	2	P_d =	0.49

Calculations Sheet 1

Developed by Bolton Menk, Inc.
for the Local Road Research Board.

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}(e^{v t_{c,G}} - v t_{c,G} - 1)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =	13.64			$t_{c,G}$ =	8.319		
v =	0.08	d_g =	11.08	v =	0.08	d_g =	3.4999

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1				crossing 2			
d_g =	11.08			d_g =	3.5		
P_d =	0.664	d_{gd} =	16.683	P_d =	0.486	d_{gd} =	7.2015

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all marked crossings and either marked or unmarked crossings at intersections, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + (P_d - \sum_{i=1}^{n} P(Y_i))d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1				crossing 2			
h =	25.0	n =	1	h =	25	n =	1
		d_p =	8.8			d_p =	5.6

M_y = motorist yield rate (decimal) M_y = 84%

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1-M_y)^{i-1}$$

2. Two-Lane Crossing

$$P(Y_1)_{i=1} = 2P_b(1-P_b)M_y + 1P_b^2 M_y^2$$

$$P(Y_i)_{i>1} = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b^2 M_y^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^3 M_y^3 + 3P_b^2(1-P_b)M_y^2) + 3P_b(1-P_b)^2 M_y}{P_d}]$$

4. Four-Lane Crossing

$$P(Y_i) = [P_d - \sum_{j=0}^{i-1} P(Y_j)] * [\frac{P_b^4 M_y^4 + 4P_b^3(1-P_b)M_y^3) + 6P_b^2(1-P_b)^2 M_y^2) + 4P_b(1-P_b^3)M_y}{P_d}]$$

Summary	
Average	14.5
LOS	C

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

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Chapter 9

Conclusion

Pedestrian crossings are an important aspect of the multi-modal transportation system that are essential to get pedestrians across highways and streets. While motorists are required to stop for pedestrians in most situations, additional measures may be appropriate at a specific crossing location.

The evaluation of uncontrolled pedestrian crossings depends on multiple factors including safety and delay, similar to the procedure for evaluation of roadways and intersections for motorists. There has been significant research into the safety of pedestrian crossings that is being applied by agencies, but the missing component has been the delay. The Highway Capacity Manual (HCM) presents a procedure for evaluating pedestrian crossing delay. As of this research study, the HCM procedure has not been widely applied to the evaluation of pedestrian crossings but can help to provide an equivalent process to vehicle intersection operational analysis and be applied to the engineering study requirement as mentioned in the MUTCD.

This report presents a procedure for the evaluation of uncontrolled pedestrian crossing locations that takes into account both safety and delay, in addition to other factors. The evaluation procedure runs through a multi-step process from field data review through the consideration of appropriate treatment options. The specific steps include

- Field Data Review
- Safety Review
- Stopping Sight Distance Analysis
- HCM Level of Service (LOS) Analysis
- Pedestrian Sight Distance Analysis
- Review of Origins and Destinations and Alternate Routes
- Review of Access Spacing and Functional Classification
- Review of Speed and Pedestrian Use
- Review of FHWA Safety Guidance
- School Crossing Considerations
- Consideration of Appropriate Treatment Options
    - Signing and Marking Treatments
    - Traffic Calming Treatments
    - Uncontrolled Crossing Treatments
    - High-Level Treatments

The background, understanding and analysis methodology of each step in the process is important to understand. The methodology presented for the evaluation of uncontrolled pedestrian crossings is available to the public and should be tailored for individual use as needed. In support of this study, a Guidebook has been developed to provide a summary of the methodology and is included in Appendix F. This Guidebook is intended to be a working document to be updated as additional research is conducted.

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Appendix A
Evaluation Flowchart

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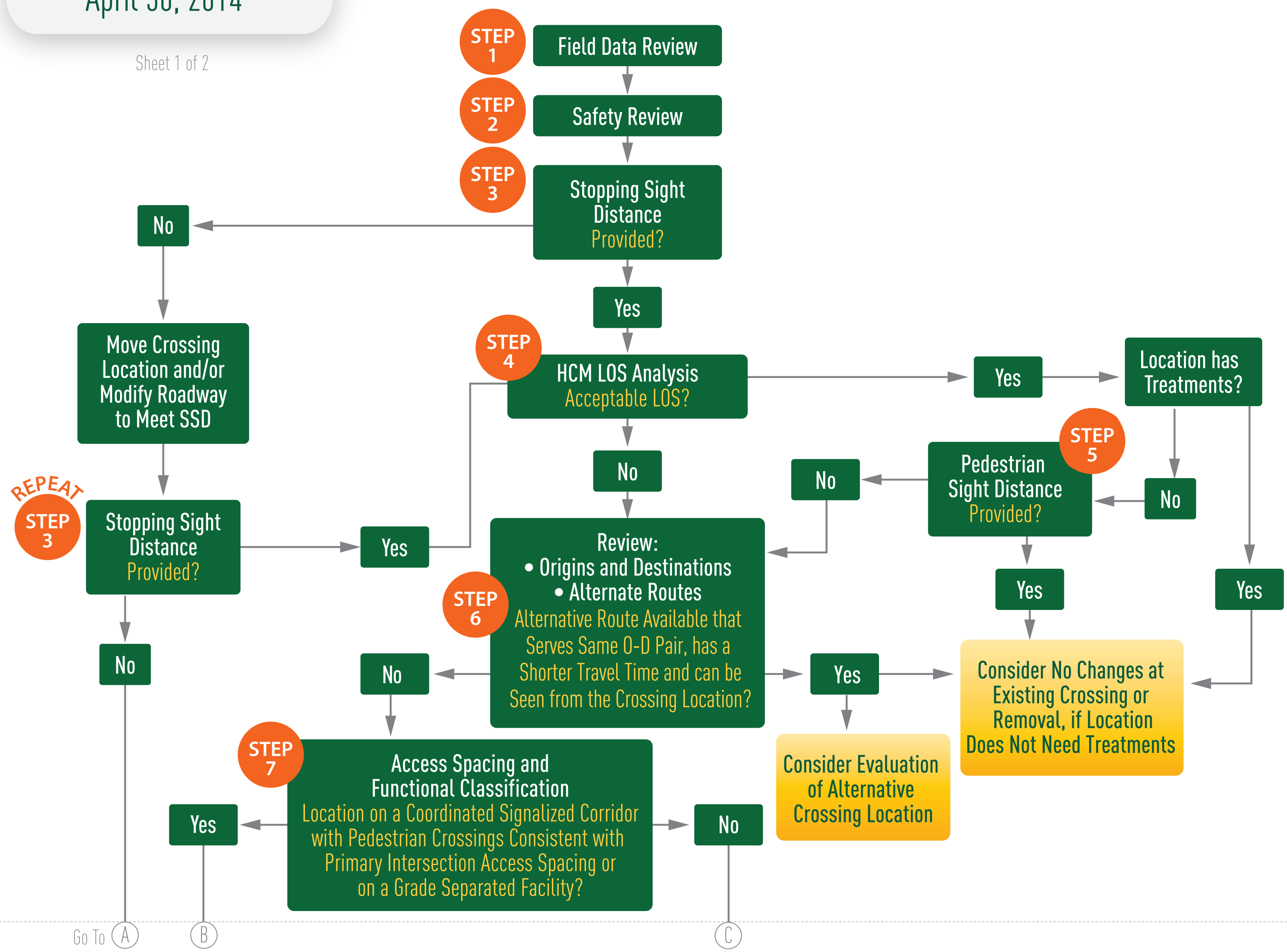
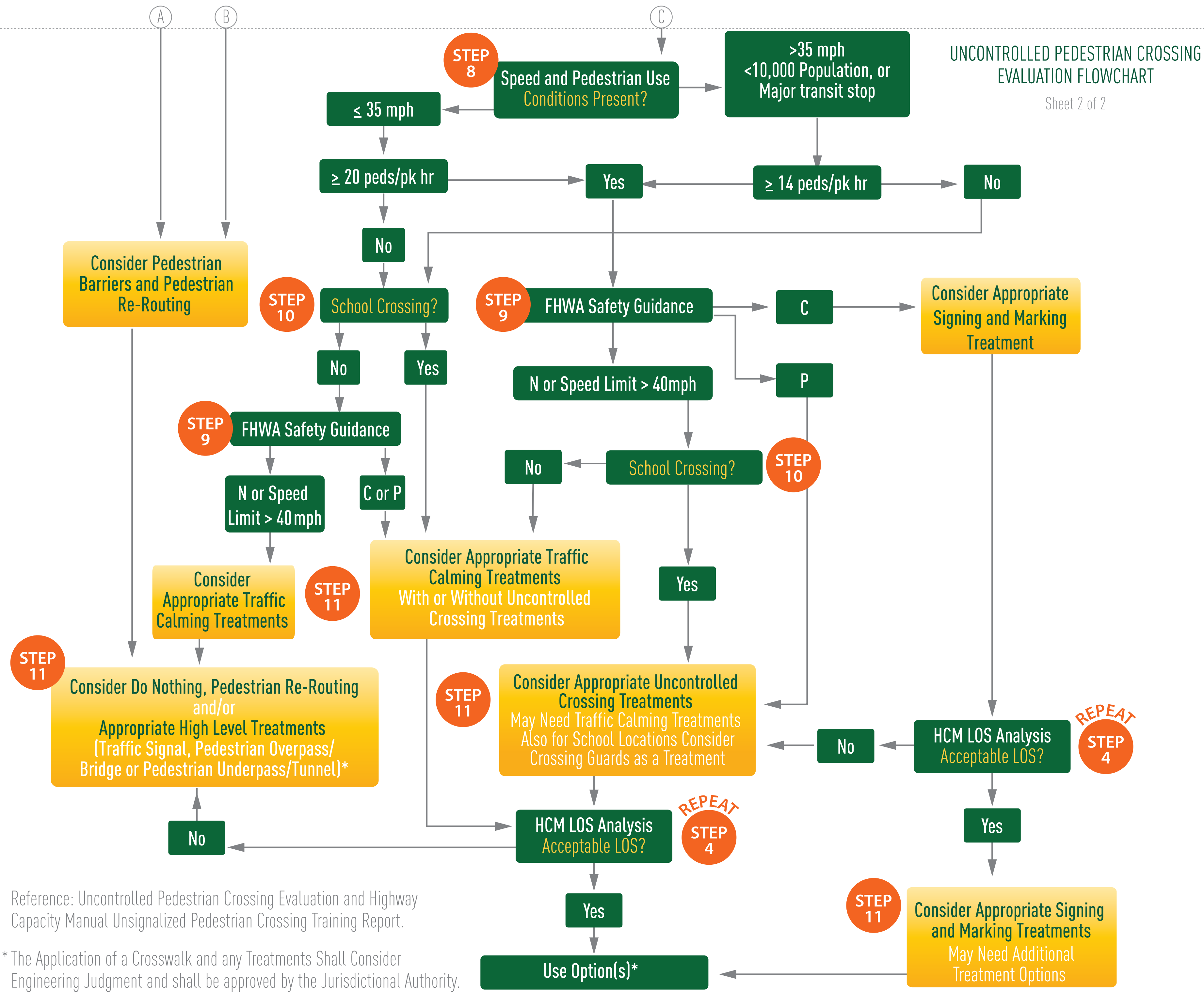
UNCONTROLLED PEDESTRIAN CROSSING EVALUATION FLOWCHART

April 30, 2014

Sheet 1 of 2





Reference: Uncontrolled Pedestrian Crossing Evaluation and Highway Capacity Manual Unsignalized Pedestrian Crossing Training Report.

* The Application of a Crosswalk and any Treatments Shall Consider Engineering Judgment and shall be approved by the Jurisdictional Authority.

Appendix B
Field Review Worksheet

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Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Location: ____________________ Date: ____________________

City, State: ____________________ Scenario: ____________________

Reviewer(s): ____________________ Agency: ____________________

Project #: ____________________ ID #: ____________________

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.

Crossing 1 ____ ft.

Crossing 2 ____ ft.

Median: width of median at crossing location ____ ft.

Crossing Width: effective crosswalk width ____ ft.

Raised Median Available? ☐ Yes ☐ No

ADA Compliant Median Available (minimum 4' x 4' landing)? ☐ Yes ☐ No

Curb Ramps Available? ☐ Yes ☐ No

ADA Compliant Curb Ramp Available (width, grades, truncated domes)? ☐ Yes ☐ No

Speed: Posted or 85th percentile speed ____ mph

Roadway Curvature and Sight Distances: Average walking speed ____ ft/s

Is the crossing location within a horizontal or vertical curve? ☐ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts		**vehicles:**	Daily		**pedestrians:**	Daily
AM Peak	Hourly		Pk 15-min	Hourly		Pk 15-min
PM Peak	Hourly		Pk 15-min	Hourly		Pk 15-min

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☐ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☐ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern? ____

Signing: Currently signed at crosswalk? ☐ Yes ☐ No

Currently signed in advance of crosswalk? ☐ Yes ☐ No

Distances? direction 1 ____ ft. direction 2 ____ ft.

Enhancements: What enhancements are currently at the crossing location? ____

Adjacent Facilities: Distance to nearest marked crosswalk? ____ ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? ____

Distance to nearest all-way stop, roundabout or signalized intersection ____ ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☐ No

Could another location serve the the movement more effectively? ☐ Yes ☐ No

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied

Notes: ______________________________

____

____

____

____

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph

L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

Appendix C
HCM Evaluation Worksheets

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2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Introduction:

The Worksheets provide a procedure for evaluating the Level of Service (LOS) at uncontrolled pedestrian crossings according to the methodology presented in Chapter 19 of the 2010 Highway Capacity Manual. Uncontrolled pedestrian crossings include: marked crossings at mid-block locations; marked crossings at intersections; and unmarked crossings at intersections, that are not controlled by a traffic control device such as signals and stop or yield signs.

Use of these Worksheets in Microsoft Excel results in an automated procedure. While this automated procedure has been checked for accuracy using multiple examples, no warranty is made by the developers as to the accuracy, completeness, or reliability of the equations and results. No responsibility is assumed for incorrect results or damages resulting from the use of these worksheets.

This process is not for use at signalized crossings and has not been verified to be accurate for unsignalized pedestrian crossings within a signalized corridor.

The equations and methodology presented through this process is contained within the 2010 Highway Capacity Manual (HCM). Any questions on the approach, assumptions, and limitations of the procedure or for verification of equations are directed to the 2010 HCM.

This material was developed by Bolton & Menk, Inc. in coordination with the Local Road Research Board (LRRB) for the use by practicioners. These Worksheets are made without charge and under no circumstances shall be sold by third parties for profit.

Submitted for Approval: May 12, 2014
Updated June 6, 2014

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations

Intersection and Mid-Block Crossings

Crossing Location:	______	Date:	______
City, State:	______	Scenario:	______
Reviewer(s):	______	Agency:	______
Project Number:	______	ID #:	______

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: ______

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing 2: ______ (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
υ_p = pedestrian flow rate (ped/s)	υ_p =	0*	υ_p =	
υ = vehicular flow rate (veh/s) = V/3600	υ =	V/3600	υ =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay		sec/ped
LOS		

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Crossing Location: ______________________ Date: ______________

City, State: ______________________ Scenario: ______________

Reviewer(s): ______________________ Agency: ______________

Step 1: Identify Two-Stage Crossings

Question		
Is there a median available for a two-stage crossing?	☐ Yes	☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)?	☐ Yes	☐ No
If yes, do pedestrians treat this as a two-stage crossing location?	☐ Yes	☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)

S_p = 3.5 ft/s
t_s = 3 sec

crossing 1				crossing 2			
L =		**t_s =**		**L =**		**t_s =**	
S_p =		**t_c =**		**S_p =**		**t_c =**	

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1				crossing 2			
v_p =		**t_c =**		**v_p =**		**t_c =**	
v =		**N_c =**		**v =**		**N_c =**	

2. compute spatial distribution:

$$N_p = INT\left[\frac{8.0(N_c - 1)}{W_c}\right]$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)

clear width, if other than 8: ______ ft.

crossing 1				crossing 2			
N_c =				**N_c =**			
W_c =		**N_p =**		**W_c =**		**N_p =**	

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1				crossing 2			
N_p =				**N_p =**			
t_c =		**$t_{c,G}$ =**		**t_c =**		**$t_{c,G}$ =**	

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{\frac{-t_{c,G} v}{L}}$$

$$P_d = 1 - (1 - P_b)^L$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of through lanes crossed
$t_{c,G}$ = group critical headway (s) = $t_{c,}$ if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1				crossing 2			
$t_{c,G}$ =				**$t_{c,G}$ =**			
v =		**P_b =**		**v =**		**P_b =**	
N =		**P_d =**		**N =**		**P_d =**	

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{vt_{c,G}} - vt_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1		crossing 2	
$t_{c,G}$ =		$t_{c,G}$ =	
v =	d_g =	v =	d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1		crossing 2	
d_g =		d_g =	
P_d =	d_{gd} =	P_d =	d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all intersections and at all marked crossings, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i-0.5)\,P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right) d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1		crossing 2	
h =	n =	h =	n =
	d_p =		d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{(2P_b(1-P_b)M_y) + (P_b{}^2 M_y{}^2)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{P_b{}^3 M_y{}^3 + 3P_b{}^2(1-P_b)M_y{}^2 + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \textstyle\sum_{j=0}^{i-1} P(Y_j)\right] \text{x} \left[\frac{P_b{}^4 M_y{}^4 + 4P_b{}^3(1-P_b)M_y{}^3 + 6P_b{}^2(1-P_b)^2 M_y{}^2 + 4P_b(1-P_b{}^3)M_y}{P_d}\right]$$

Summary	
Average	
LOS	

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Determine if there is a crossing treatment used that could provide vehicle yielding. This then provides a possible reduction in delay.

Motorist Yield Rate = M_y

Crossing Treatment	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate
Crosswalk Markings and Signs Only [(1)]	7%	7%
Median Refuge Islands [(1)]	34%	29%
Pedestal Mounted Flashing Beacon (2-Lane, 35 mph) [(3)]	N/A	57%
Overhead Flashing Beacon (push-button activation) [(1)]	47%	49%
Overhead Flashing Beacon (passive activation) [(1)]	31%	67%
Pedestrian Crossing Flags [(1)]	65%	74%
School Crossing Guards [(5)]	N/A	86%
In-street Crossing Signs (25-30 mph) [(1)]	87%	90%
Warning Sign with Edge Mounted LEDs [(6)]	N/A	28%
In-road warning lights [(1)]	N/A	66%
High-visibility Signs and Markings (35 mph) [(1)]	17%	20%
High-visibility Signs and Markings (25 mph) [(1)]	61%	91%
Rectangular Rapid-Flash Beacon (RRFB) [(2)(4)]	84%	81%
School Crossing Guards with RRFB [(5)]	N/A	91%
Pedestrian Hybrid Beacon (HAWK) [(1)]	97%	99%

N/A: No Research Found on Effect to Yielding Rate

Sources: (1) Fitzpatrick, K., S.M. Turner, M. Brewer, P.J. Carlson, B. Ullman, N.D. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.

(2) Lewis, R., J.R. Ross, D.S. Serpico : Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.

(3) Bolton & Menk Field Data Collection

(4) Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.

(5) Brewer, Marcus A., Kay Fitzpatrick. Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

(6) Kipp, Wendy M.E., Jennifer M. V. Fitch. Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report. Vermont Agency of Transportation, Report 2011-3, Montpelier, VT, February 2011. (Rate Normalized to High Visibility Markings and Signs at 35 mph)

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Appendix D
FHWA Safety Guidance Table

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Table 11. Recommendations for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations.*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT >9,000 to 12,000			Vehicle ADT >12,000–15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)	≤ 48.3 km/h (30 mi/h)	56.4 km/h (35 mi/h)	64.4 km/h (40 mi/h)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median***	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.

** Where the speed limit exceeds 64.4 km/h (40 mi/h), marked crosswalks alone should not be used at unsignalized locations.

*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more indepth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

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Appendix E
Treatment Tables

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Signing and Marking Treatments
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate: Staged Pedestrian	Motorist Yield Rate: Unstaged Pedestrian	Cost
Crosswalk Markings Only	Inexpensive Helps define a crossing location Indicates to drivers that a crossing location is present	Very little effect at night Speeds increase over time Not been shown to reduce crashes	Not usually recommended alone Low volume and low speed roadways Where justified	NR	NR	$500 to $2,000
Warning Signs	Inexpensive Helps define a crossing location Warning to drivers that a crossing location is present	Tend to be ignored unless pedestrians use the crossing consistently Proven to be ineffective at reducing crashes at uncontrolled intersections	Where unexpected entries into the roadway by pedestrians may occur Either at or before the crossing location Either with or without a marked crosswalk	NR	NR	$300 to $1,200
Overhead Warning Signs	Visual distance increased Warning to drivers that a crossing location is present Signs easier to see when have multiple lanes of approach	Requires overhead structure Tend to be ignored unless pedestrians use the crossing consistently	Multi-lane roadways Midblock crossing locations Usually coupled with other measures such as RRFBs or beacons	NR	NR	$60,000 to $75,000
Colored Concrete/Brick Pavers	May decrease vehicle speed	Can be expensive Not been shown to reduce crashes Speeds increase over time	Downtown/Urban conditions Traffic signal locations In conjunction with pavement markings	NR	NR	$10,000 to $75,000
Crosswalk Markings and Signs	Inexpensive Warning to drivers that a crossing location is present May decrease vehicle speed	Very little effect at night Not been shown to reduce crashes Speeds increase over time	Where justified	7%	7%	$800 to $3,200
In-Street Crossing Signs (25 to 30 mph)	Inexpensive Additional Warning to drivers that a crossing location is present	May make snow removal more difficult Need consistent maintenance and replacement due to vehicle hits	Downtown/Urban conditions Supplement warning signs at high pedestrian volume locations In conjunction with pavement markings	87%	90%	$500 to $1,000
High Visibility Crosswalk Markings	May decrease vehicle speed	Not been shown to reduce crashes Speeds increase over time	Where justified Urban conditions	61% (25mph) 17% (35 mph)	91% (25 mph) 20% (35 mph)	$5,000 to $50,000

NR = No Research Found on Effect to Yielding Rate

Uncontrolled Crossing Treatments (in conjunction with markings and signs)
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate: Staged Pedestrian	Motorist Yield Rate: Unstaged Pedestrian	Cost
Center Median with Refuge Island	Decreases pedestrian crossing distance Provides higher pedestrian visibility Reduces vehicle Speeds approaching the island Reduces conflicts Increases usable gaps Reduces pedestrian exposure time	May make snow removal more difficult May be a hazard for motorists Small islands not recommended on high speed (>40 mph) roadways	Wide two-lane roads and multi-lane roads with sufficient right-of-way	34%	29%	Variable depending on length
School Crossing Guards	Inexpensive Provides higher pedestrian visibility to drivers Highlights when a pedestrian crossing is being used	May require trained staff or local law enforcement, especially on high speed and high volume roadways	At school locations	NR	86%	Variable
Pedestrian Crossing Flags	Inexpensive Provides higher pedestrian visibility to drivers assuming the flag is held In a noticeable location	No effect at night Requires pedestrian to actively use a flag Can be easily removed/stolen Shorter crossings are preferred	Downtown/Urban locations High pedestrian volume locations Across low speed (<45 mph) roadways	65%	74%	<$500
Warning Sign with Edge Mounted LEDs	Highlights a crossing both at night and during the day	Requires pedestrian activation Minimal to no effect on speed	In conjunction with In-Road Warning Lights Downtown/Urban conditions	NR	28%	$3,000 to $8,000
In-Road Warning Lights	Highlights a crossing both at night and during the day Provides higher driver awareness when a pedestrian is present	Snow plows can cause maintenance issues No effect when road surface is covered In snow Requires pedestrian activation	Downtown/Urban conditions	NR	66%	$20,000 to $40,000
Pedestal Mounted Pedestrian Flashing Signal Beacons	Provides higher driver awareness when a pedestrian is present	Requires pedestrian activation Not advisable on multi-lane streets Not been shown to reduce crashes	Low speed school crossings Two lane roadways Midblock crossing locations	NR	57% (2-Lane, 35 mph)	$12,000 to $18,000
Pedestrian Overhead Flashing Signal Beacons	Provides higher driver awareness when a pedestrian is present	Requires pedestrian activation	Multi-lane roadways Midblock crossing locations Lower speed roadways	active 47% passive 31%	active 49% passive 67%	$75,000 to $150,000
Rectangular Rapid Flash Beacons (RRFBs)	Provides higher driver awareness when a pedestrian is present Increases yielding percentage increase In usable gaps Reduces the probability of pedestrian risk taking Can be configured to be seen from 360 degrees	Requires pedestrian activation	Supplement existing pedestrian crossing warning signs School Crossings Midblock crossing locations Low and high speed roadways	84%	81%	$12,000 to $18,000

NR = No Research Found on Effect to Yielding Rate

Traffic Calming Treatments

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate: Staged Pedestrian	Motorist Yield Rate: Unstaged Pedestrian	Cost
Center Median with Refuge Island	Decreases pedestrian crossing distance Provides higher pedestrian visibility Reduces vehicle speeds approaching the island Reduces conflicts Increases usable gaps Reduces pedestrian exposure time	May make snow removal more difficult May be a hazard for motorists Small islands not recommended on high speed (>40 mph) roadways	Wide two-lane roads and multi-lane roads with sufficient right-of-way	34%	29%	Variable depending on length
Raised Crossings	Provides higher pedestrian visibility to vehicles Can reduce vehicle Speeds	May make snow removal more difficult May reduce emergency vehicle response times Only appropriate In Low speed/Urban environments	Low speed/Urban environments	NR	NR	$5,000 to $25,000
Lighting	Can be inexpensive Highlights a crossing at night	No effect during daylight	Targeted crossing locations not located on a street with continuous roadway	NR	NR	$1,000 to $40,000
Pavement Striping (Road Diet)	Can be inexpensive May decrease vehicle speed May decrease illegal right side passing Can be an interim solution	Does not provide a physical barrier between modes Pedestrian crossing distance same as existing	Four-lane undivided roadways Locations with very long crossings	NR	NR	Variable depending on length
Curb Bump-Outs/Extensions	Can be inexpensive Reduces pedestrian crossing distance Provides higher pedestrian visibility to vehicles Reduces speed for turning vehicles Decrease in illegal right side passing	May make snow removal more difficult Proximity of curb to through traffic may be a safety concern	Downtown/Urban conditions	NR	NR	$5,000 to $15,000 per crossing
Channelized Turn Lanes (Corner Islands) (Not Usually Recommended as a Pedestrian Crossing Treatment)	Decrease pedestrian crossing distance Provides higher pedestrian visibility Decrease in illegal right side passing	May require new pavement Can be more challenging for visually impaired pedestrians Right turning drivers often fail to yield to pedestrians Can increase right turn vehicle speeds May make snow removal more difficult Vehicle crashes may increase	Intersections with wide approaches Intersections with right turn lanes and sufficient corner right-of-way Intersections with operational improvement needs	NR	NR	$50,000 to $100,000 per intersection

NR = No Research Found on Effect to Yielding Rate

High Level Treatments
(Treatments Should be Justified Through an Engineering Study)

Treatment	Advantages	Disadvantages	Recommended Locations	Motorist Yield Rate		Cost
				Staged Pedestrian	Unstaged Pedestrian	
Pedestrian Hybrid Beacon	Provides higher driver awareness when a pedestrian is present Has been shown to decrease pedestrian crashes	Potential increase in vehicle crashes Can have spotty compliance rates due to a lack of driver understanding	Justified locations Midblock crossing locations	97%	99%	$150,000 to $300,000
Traffic Signal	Provides higher driver awareness when a pedestrian is present Easily understandable	May increase crashes due to the driver expectation of a green signal indication	High pedestrian volume crossings Justified locations, meets signal warrants	NA	NA	$100,000 to $300,000
Underpass Grade Separation	Removes pedestrian/vehicle conflicts	Potential of the crossing not being used Very location specific Very expensive Drainage within an underpass can be problematic Underpass would require lighting	Location with compatible grades High pedestrian volume crossings High volume roadways High speed roadways	NA	NA	$800,000+
Overpass Grade Separation	Removes pedestrian/vehicle conflicts	Potential of the crossing not being used Very location specific Very expensive Snow removal on overpass may be difficult	Location with compatible grades High pedestrian volume crossings High volume roadways High speed roadways	NA	NA	$1,200,000+

NA = Not Applicable or No Research Found on Effect to Yielding Rates

Appendix F
Guidebook

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Pedestrian Crossings: *Uncontrolled Locations*

MINNESOTA DEPARTMENT OF TRANSPORTATION

MINNESOTA LTAP
CENTER FOR TRANSPORTATION STUDIES
UNIVERSITY OF MINNESOTA

BOLTON & MENK Engineers & Surveyors

LRRB LOCAL ROAD RESEARCH BOARD

Pedestrian Crossings: Uncontrolled Locations

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Document Information and Disclaimer

The information presented in this guidebook is provided as a resource to assist agencies in their efforts to evaluate uncontrolled pedestrian crossings and determine appropriate treatment options. The evaluation procedure provided in this guidebook takes into account accepted practice, safety, and operations.

Pedestrian crossings are an important feature of the multimodal transportation system. They enable pedestrians and bicyclists to cross conflicting traffic so they can access locations on either side of streets and highways. Pedestrian crossings can be either marked or unmarked and can be placed at intersections or mid-block locations. Uncontrolled pedestrian crossings are crossing locations that are not controlled by a stop sign, yield sign, or traffic signal.

This guidebook is a summary of the evaluation procedured presented in the *Uncontrolled Pedestrian Crossing Evaluation and Highway Capacity Manual Unsignalized Pedestrian Crossing Training Report*.

This guidebook considers best practices in pedestrian crossing evaluation by the Federal Highway Administration, the Minnesota Department of Transportation, the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board, and other research. The information is intended to offer agencies a consistent methodology for evaluating uncontrolled pedestrian crossing locations on their roadways that considers both safety and delay.

The final decision to implement the evaluation methodology or any of the crossing location treatment strategies presented in this guidebook resides with the agency. There is no expectation or requirement that agencies implement this evaluation strategy, and it is understood that actual implementation of the evaluation decisions will be made by agency staff.

It is the responsibility of agencies to determine if the procedure presented in this guide is appropriate and consistent with their needs.

- This guidebook does not set requirements or mandates.
- This guidebook contains no warrants or standards and does not supersede other publications that do.
- This guidebook is not a standard and is neither intended to be, nor does it establish, a legal standard of care for users or professionals.
- This guidebook does not supersede the information in publications such as:
    - Minnesota Manual on Uniform Traffic Control Devices
    - AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities
    - Minnesota's Best Practices for Pedestrian/Bicycle Safety
    - Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments
    - 2010 Highway Capacity Manual

Introduction and Background

According to 2013 Minnesota State Statutes, "where traffic-control signals are not in place or in operation, the driver of a vehicle shall stop to yield the right-of-way to a pedestrian crossing the roadway within a marked crosswalk or at an intersection with no marked crosswalk." Additionally, "Every pedestrian crossing a roadway at any point other than within a marked crosswalk or at an intersection with no marked crosswalk shall yield the right-of-way to all vehicles upon the roadway."

Although the state statute says that motorists should stop for a pedestrian within a marked crosswalk or crossing at an intersection, in practice motorists do not always stop for pedestrians and yield the right-of-way. Additionally, at locations with high traffic volumes, there may not be adequate gaps in the traffic stream to allow pedestrians to safely cross. These situations can result in crossings that are challenging to navigate and cause long delays for pedestrians, which may lead to a high risk-taking environment and decrease safety.

Pedestrian crossing treatments that either reduce the crossing distance or increase driver yield rates have been shown to reduce the potential delay experienced by a pedestrian. While state statutes support the rights of pedestrians at all intersections and marked crosswalks, it is a small comfort when a crash between a vehicle and a pedestrian occurs because a motorist failed to stop and yield the right-of-way.

Providing safe crossing situations for pedestrians relies on placing crosswalks and other pedestrian crossing treatments at appropriate locations in a way that also results in minimal pedestrian delay. The Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD) states that crosswalk pavement markings should not be placed indiscriminately and an engineering study should be completed when crosswalk markings are being contemplated at a crossing.

Defining where to place pedestrian crossing facilities—including markings, signs, and/or other devices—depends on many factors, including pedestrian volume, vehicular traffic volume, sight lines, and speed. This guidebook presents a methodology for the evaluation of pedestrian crossing locations that takes into account both pedestrian safety and delay.

Sources:
State of Minnesota, "2013 Minnesota Statutes 169.21 Pedestrian," 2013. Available: *https://www.revisor.mn.gov/statutes.* [Accessed January 2014].
Minnesota Department of Transportation, Minnesota Manual on Uniform Traffic Control Devices, Roseville, MN: MnDOT, January 2014.

Pedestrian Crossing Evaluation Methodology

The evaluation of a pedestrian crossing location should be thoroughly documented. This includes not only the location details, evaluation, decisions, and design process, but also any stakeholder involvement and public comments. The evaluation methodology presented is based on research on the safety of pedestrian crossings and the procedure developed in the 2010 *Highway Capacity Manual* on pedestrian delay.

The jurisdictional authority has the final decision on the control and design of pedestrian crossing facilities and features on their roadways.

The evaluation methodology guidance is shown in the flowchart on pages 6–7.

STEP 1

Field Data Review

A Data Collection Field Review Worksheet is provided at the end of this guidebook (pages 28–29). The field data review should consider and collect information about the following elements:

GEOMETRICS

Crossing Length

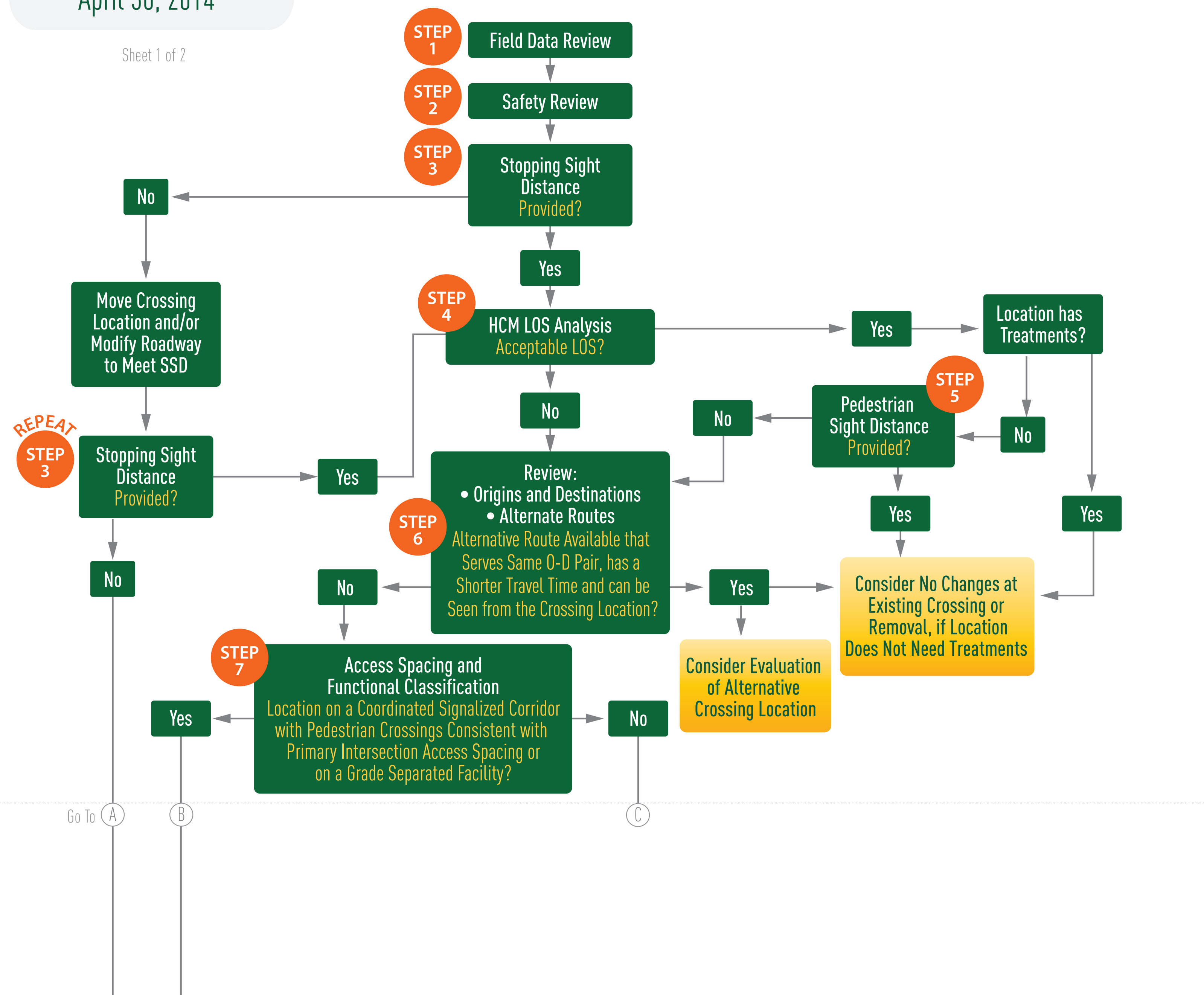
- Shorter pedestrian crossing lengths are preferred by pedestrians.
- The crossing length (L) is measured from curb face to curb face and is the total length a pedestrian is exposed to conflicting traffic (as shown at right).
- If there is a median, two separate crossing lengths are measured.
- Pedestrian exposure is reduced on shorter crossings.

MEASURING CROSSING LENGTH

UNCONTROLLED PEDESTRIAN CROSSING EVALUATION FLOWCHART

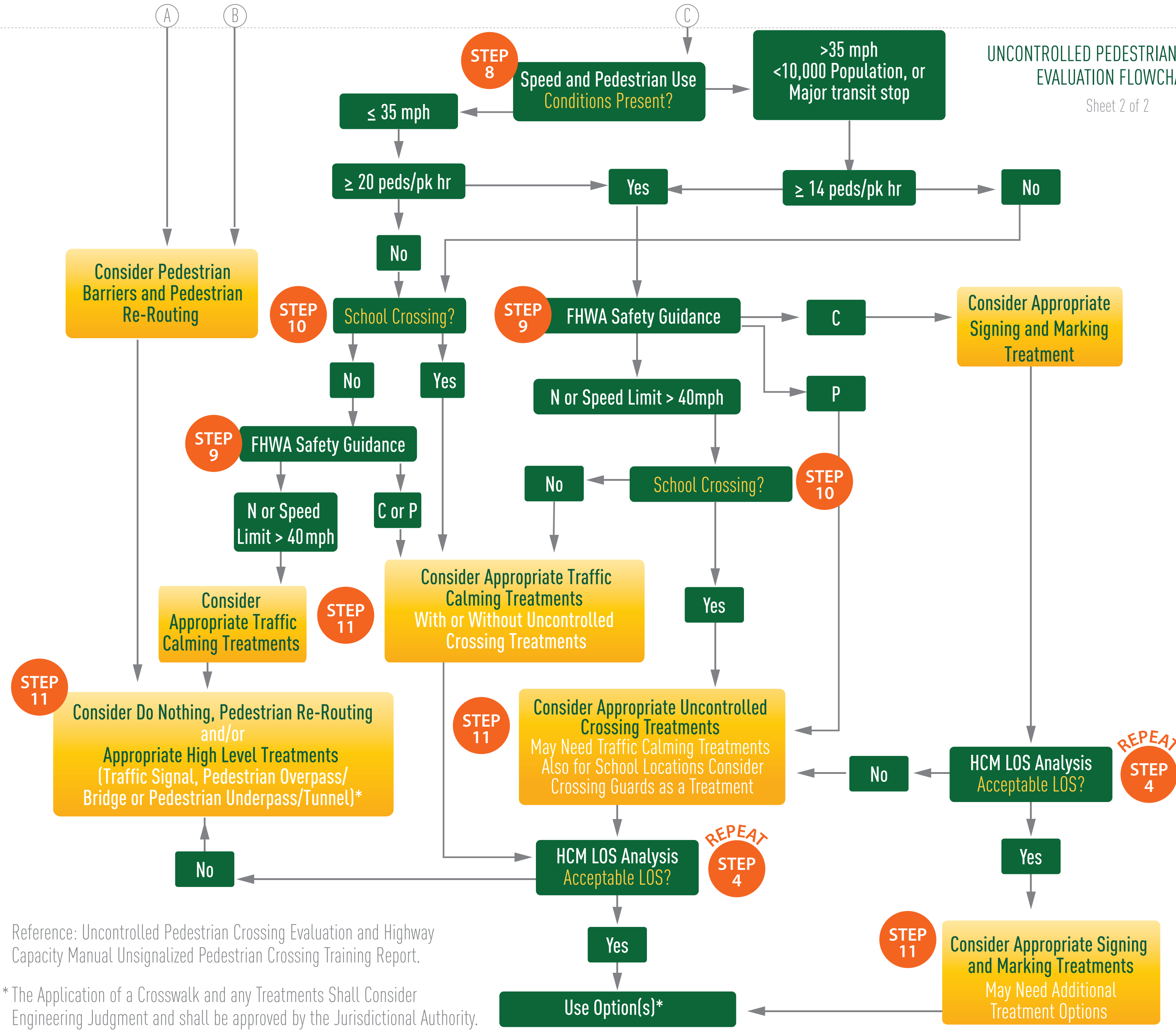
April 30, 2014

Sheet 1 of 2



UNCONTROLLED PEDESTRIAN CROSSING EVALUATION FLOWCHART

Sheet 2 of 2

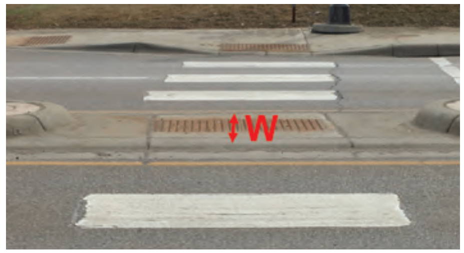


Reference: Uncontrolled Pedestrian Crossing Evaluation and Highway Capacity Manual Unsignalized Pedestrian Crossing Training Report.

* The Application of a Crosswalk and any Treatments Shall Consider Engineering Judgment and shall be approved by the Jurisdictional Authority.

Median Width

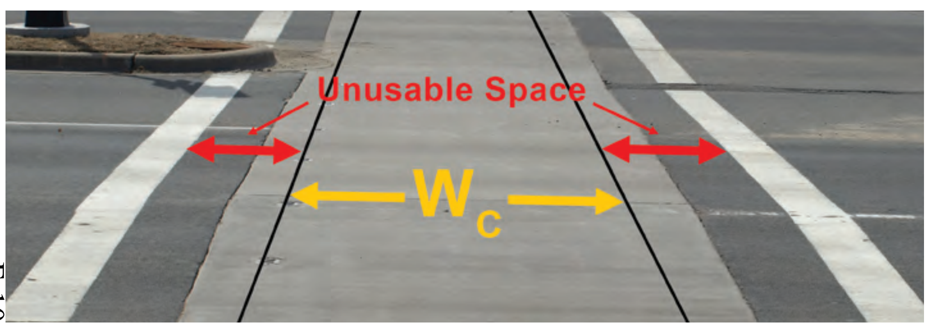
- A median wider than 6 feet can provide a refuge space for pedestrians.
- A wider median is preferred by pedestrians.
- The median width (W) is measured from curb face to curb face (as shown below).
- A median should be sufficiently sized to handle the pedestrians using it.



MEASURING MEDIAN WIDTH

Crosswalk Width

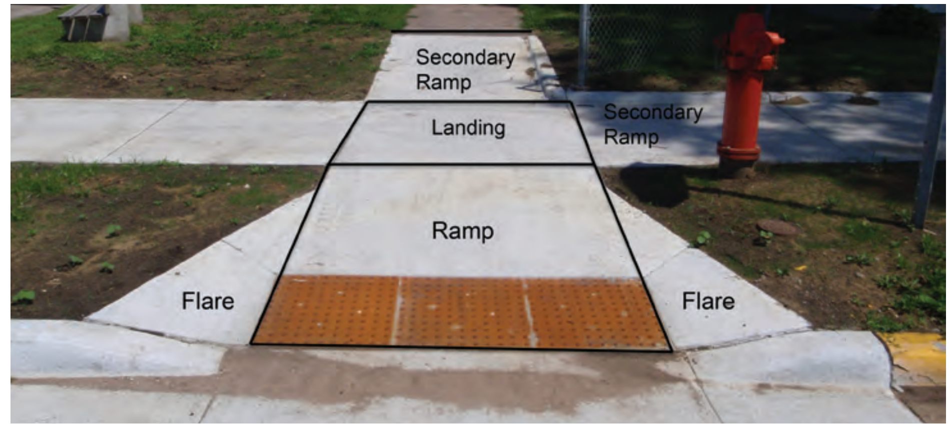
- Crosswalk width provide a defined area in which to cross.
- Effective crosswalk width is measured at the narrowest point of the crossing, be it in the ramp or the crosswalk.
- Crosswalk width (W_c) is the width measurement of at the narrowest point of the crossing (as shown at right), unless other space is usable by pedestrians (i.e., in downtown locations).



MEASURING CROSSWALK WIDTH

Curb Ramps

- Curb ramps provide equal access to all users.
- Pedestrian curb ramps are required for all pedestrian crossing locations.



CURB RAMP DIAGRAM

Americans with Disabilities Act (ADA) Requirements

- ADA requirements for pedestrian crossings include grades, tactile surfaces/truncated domes, ramp width, and landing areas.
- The requirements are expansive and are beyond the scope of this guidebook.
- Please see the Minnesota Department of Transportation Accessibility Design Guidance, *http:///www.dot.state.mn.us/ada/design.html*, for detailed information.

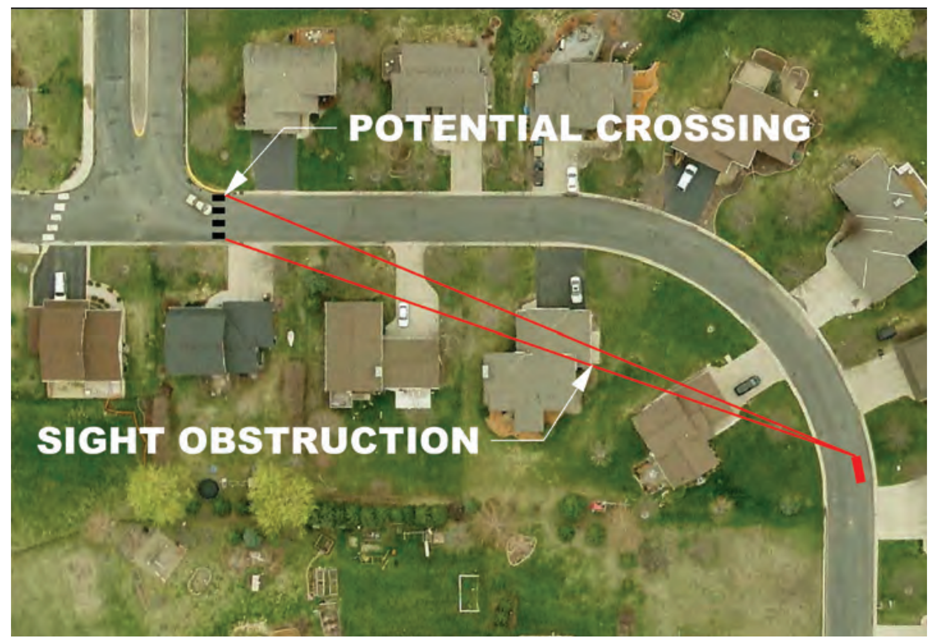
Sources:
Minnesota Department of Transportation, "Accessibility and MnDOT," [Online]. Available: *http://www.dot.state.mn.us/ada/index.html.* [Accessed November 2013].

Roadway Speed

- Slower speeds are preferred by pedestrians.
- The speed of a vehicle directly impacts the sight distance needed and the braking time of a vehicle.
- The speed (S) is used to determine the stopping sight distance. The speed should be the 85th percentile speed of the roadway being crossed. In the absence of collected speed data, it is assumed that the 85th percentile speed is equal to the speed limit.
- Slower speeds have been shown to reduce the possibility of a fatal crash in pedestrian/vehicle crashes based on study results by the Washington State Department of Transportation, as shown in the chart below.

Roadway Curvature

- The vertical and horizontal curvature of a roadway can impact sight lines for both motorists and pedestrians.
- For more information on vertical and horizontal curvature, please see the American Association of State Highway and Transportation Officials: A Policy on Geometric Design of Highways and Streets (AASHTO Green Book).



SIGHT OBSTRUCTION CAUSED BY ROADWAY CURVATURE

Sources:
A. V. Moudon, L. Lin and P. Hurvitz, “Managing Pedestrian Safety I: Injury Severity,” Washington State Department of Transportation, Olympia, WA, February 2007.

Stopping Sight Distance

- Stopping sight distance (SSD) is the distance covered by a vehicle during a stopping procedure. SSD should be provided at all pedestrian crossings.
- The SSD considers both brake reaction distance and braking distance.

$$SSD = 1.47St + 1.075\frac{S^2}{30\left[\left(\frac{a}{32.2}\right) \pm G\right]}$$

Where:

SSD = stopping sight distance
S = speed (mph)
t = brake reaction distance, 2.5 s
a = deceleration rate, ft/s^2, default = 11.2 ft/s^2
G = grade, rise/run, ft/ft

For more information on SSD, please see the AASHTO Green Book.

Pedestrian Sight Distance

- While Minnesota State Statute requires that motorists stop for pedestrians legally crossing, many pedestrians wait for an adequate gap in traffic before crossing.
- Pedestrian sight distance (PedSD) is a term to describe the distance covered by a motorist during the time it takes a pedestrian to recognize an adequate gap in traffic and cross the roadway.

$$PedSD = 1.47S\left(\frac{L}{S_p} + t_s\right)$$

Where:

$PedSD$ = pedestrian crossing sight distance
S = design speed (mph)
L = crossing distance (ft)
S_p = average pedestrian walking speed (ft/s), default = 3.5 ft/s
t_s = pedestrian start-up and end clearance time (s), default = 3.0 s

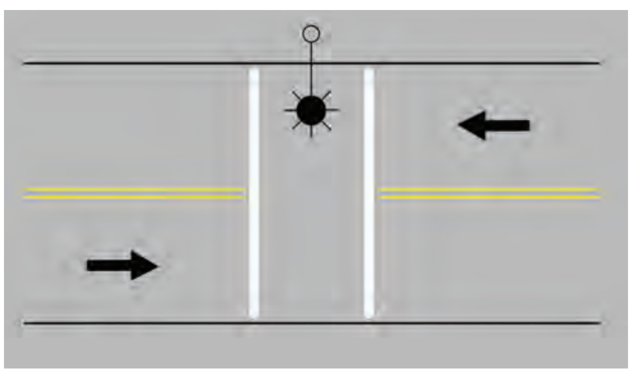
Traffic and Pedestrian Data

- The volume of vehicles on the roadway directly affects the number of gaps available for pedestrians to cross a roadway.
- The volume of pedestrians using the crossing affects how motorists view the crossing. A highly used crossing may be more recognizable to a motorist, resulting in a safer crossing.

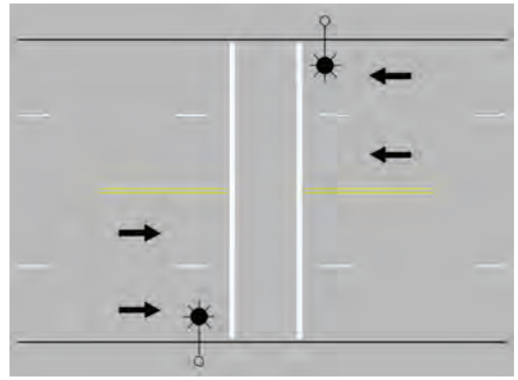
ADDITIONAL SITE CHARACTERISTICS

Lighting

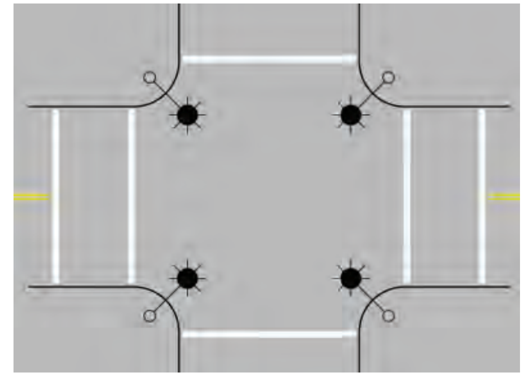
- Lighting should be provided at intersection crossings and marked crossings that are used at night.
- Intersection or pedestrian scale lighting may be appropriate to light the pedestrian crossing location.
- Continuous street lighting can provide adequate lighting of pedestrian facilities but may need to be supplemented at pedestrian crossing locations.
- Lighting should follow the recommended levels provided in the AASHTO Roadway Lighting Design Guide.
- Lighting should provide positive contrast if possible.
- Positive contrast lights the pedestrian from the front so they are more easily seen by approaching motorists.
- Examples of lighting configurations are shown in the diagrams below and at right.



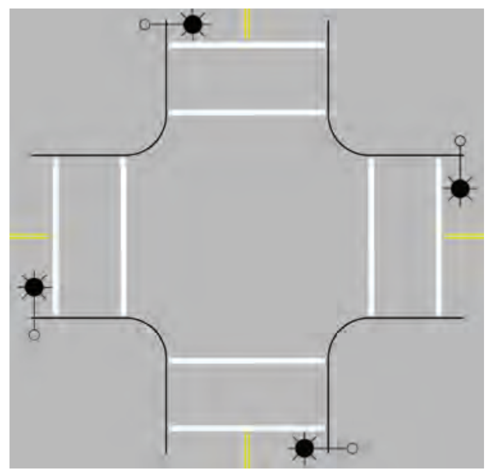
TWO LANE MID-BLOCK CROSSING LIGHTING



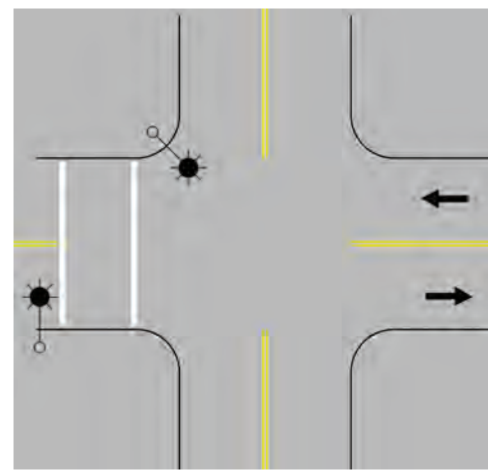
MULTI-LANE OR LONG MID-BLOCK CROSSING LIGHTING



TRADITIONAL INTERSECTION LIGHTING (ALL LEGS)



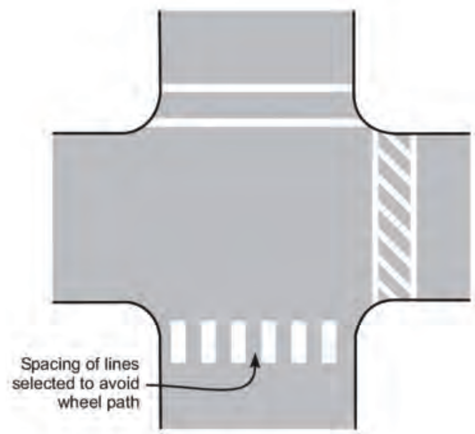
PEDESTRIAN CROSSING INTERSECTION LIGHTING (ALL LEGS)



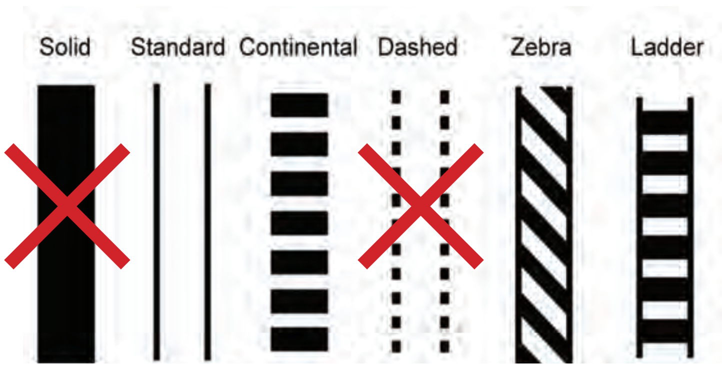
PEDESTRIAN CROSSING INTERSECTION LIGHTING (ONE LEG)

Crosswalk Pavement Markings

- Crosswalk markings shall follow the designs as stated in the MN MUTCD.
- High-visibility crosswalk markings include continental, zebra, and ladder (examples shown below and at right). Markings should be in good to excellent condition and highly visible to approaching traffic.



CROSSWALK MARKING EXAMPLES



ACCEPTABLE CROSSWALK MARKING PATTERNS

STANDARD/TRANSVERSE CROSSWALK PAVEMENT MARKINGS

CONTINENTAL CROSSWALK PAVEMENT MARKINGS

Signing

- Signing shall follow the design and placement as stated in the MN MUTCD.
- Signing options are shown in the images below.

PEDESTRIAN CROSSING WARNING SIGN PLUS IN-ROAD SIGNS

SCHOOL CROSSING WARNING SIGN

Sources:

Minnesota Department of Transportation, Minnesota Manual on Uniform Traffic Control Devices, Roseville, MN: Minnesota Department of Transportation, January 2014.

C. V. Zeeger, J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes and B. Campbell, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines," Federal Highway Administration, McLean, VA, September 2005.

Distance to Adjacent Pedestrian Crossing Facilities

- If there is a nearby pedestrian crossing facility that can serve the same movements with a shorter travel time—and if this nearby crossing facility can be seen from the crossing location being studied—the crossing location being studied may not be needed.
- In some cases, an existing pedestrian crossing may not serve the pedestrian movements of the area and should be moved to a more appropriate location.
- The other location may actually provide a shorter travel time when considering the time waiting to cross.
- If pedestrians are already crossing at a location, they are unlikely to choose to cross at another location unless it is shorter, regardless of safety. It is important to provide crossings at locations where pedestrians are already crossing, or consider creating physical barriers if safety can be achieved and direction to a nearby crossing is provided.

Distance to Adjacent Intersections with All-Way Stop, Signal, or Roundabout Control

- An adjacent controlled crossing location may provide a shorter travel time when considering the time waiting to cross.

Origins and Destinations

- Review pedestrian paths between nearby origins and destinations.
- Typical origins and destinations of importance include:
  - Bus stops to businesses and residences
  - High-density residential to bus stops and commercial/retail
  - Hospitals and medical centers to bus stops and parking
  - Retirement communities to bus stops and commercial retail
  - Schools/colleges/universities to housing and parking
  - Parks to residences
  - Recreational/community centers to residences and parking
  - Theatres and museums to parking
  - Trails to parks and other trails
  - Commercial/retail space to parking

STEP 2 Safety Review

The safety review includes evaluating the crash records for the crossing location. Pedestrian crashes may necessitate a more in-depth look at the issues and concerns at a crossing location.

Rear-end crashes at a location may indicate that motorists are stopping for pedestrians, but they may also indicate that there is inadequate stopping sight distance. Other types of crashes should be reviewed to determine if the conflicts are impacting the crossing safety and if they indicate other intersection concerns.

STEP 3 Stopping Sight Distance

Every pedestrian crossing location should have adequate stopping sight distance (SSD). If adequate SSD cannot be provided at a potential crossing location, the location may not be suitable for a pedestrian crossing. Adequate SSD ensures that most motorists under normal conditions will be able to stop for a pedestrian that has entered the roadway.

If adequate SSD is not provided, consider pedestrian barriers and pedestrian routing to alternate crossing locations.

STEP 4 HCM Level of Service Analysis

To determine the level of service (LOS) of the current crossing condition, follow the procedure outlined in the 2010 *Highway Capacity Manual*. The methodology follows a six-step program, as shown below.

Step 1: Identify Two-Stage Crossings

↓

Step 2: Determine Critical Headway

↓

Step 3: Estimate Probability of a Delayed Crossing

↓

Step 4: Calculate Average Delay to Wait for Adequate Gap

↓

Step 5: Estimate Delay Reduction due to Yielding Vehicles

↓

Step 6: Calculate Average Pedestrian Delay and Determine LOS

This six-step procedure to determine LOS for pedestrians at uncontrolled crossing locations is provided in the worksheets at the end of this guidebook (pages 30–34).

The input information for use in the equations is provided in the input table on the second worksheet. An explanation of measuring crosswalk length (L) and crosswalk width (W_c) can be found on page 4 of this guidebook.

LOS is generally deemed acceptable between A and D and deemed unacceptable at E or F. Local agency direction on acceptable service levels should be verified. If the LOS is acceptable and the location already has treatments such as signing and/or striping, consider making no changes at the existing crossing.

If LOS is unacceptable, skip to Step 6. If this procedure is completed after Step 11, consider applying appropriate treatment option(s) if LOS is acceptable. If LOS is deemed acceptable, consider making no changes at the crossing or possibly removing treatments if they are not needed.

STEP 5 Pedestrian Sight Distance

If adequate service levels are provided, pedestrian sight distance (PedSD) should be checked if the crossing is absent of any treatment options. This indicates that the crossing is unmarked and unsigned. If adequate PedSD is provided, consider no changes at the existing crossing.

STEP 6 Review: Origins and Destinations, Alternate Routes

The potential origins and destinations in the area should be reviewed for the most likely path to see how it lines up with the crossing being analyzed. The most important thing to remember is that pedestrians will take the shortest possible route. Understanding this is essential to understanding why a route is being used, especially when there are alternatives available that may actually be safer and provide less delay. In some cases, existing crossings may not actually be placed in locations where pedestrians are using them if the understanding of origins and destinations is incorrect.

Check to see if an alternative route can serve the same movements effectively while providing less delay. This includes the time to traverse to the alternative crossing, cross, and complete the movement to the destination. Average wait time at signals should be added into the equation if the crossing requires traversing a traffic signal.

If the primary origin-destination movements can be accomplished effectively at another crossing without much backtracking, consider making no changes at the existing crossing or adding pedestrian channelization and/or wayfinding. Also consider evaluating the alternate crossing location.

Sources:

American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets, 6th Edition, Washington DC: American Association of State Highway and Transportation Officials, 2011.

C. V. Zeeger, J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes and B. Campbell, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines," Federal Highway Administration, McLean, VA, September 2005.

Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington, DC: National Academy of Sciences, 2010.

STEP 7 Access Spacing and Functional Classification

The functional classification of the roadway and the current access control of the roadway being crossed should be considered.

Roadways that carry more than 12,000 vehicles per day and are classified as high-mobility corridors are generally not candidates for marked uncontrolled pedestrian crossings. Marked uncontrolled pedestrian crossings should only be implemented on signalized roadway corridors if the spacing between the signalized intersections does not adequately serve the pedestrian traffic in the community.

The spacing of pedestrian crossing facilities should follow the access spacing guidelines for signals and primary intersections on the corridor of interest. Primary access intersections are intersections that will remain full access over time while secondary access intersections may provide full or limited access over time.

Due to the limited access along grade-separated roadway facilities, marked and unmarked pedestrian crossings on those facilities are limited to interchanges, tunnels, and bridges. The high speed of the facilities, along with the driver expectations for conflicts, makes any at-grade crossing a safety concern.

Sources:
C. V. Zeeger, J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes and B. Campbell, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines," Federal Highway Administration, McLean, VA, September 2005.
K. Fitzpatrick, S. Turner, M. Brewer, P. Carlson, B. Ullman, N. Trout, E. S. Park and J. Whitcare, "Improving Pedestrian Safety at Unsignalized Crossings," Transportation Research Board of the National Academies, Washington, DC, 2006.

STEP 8 Speed and Pedestrian Use

Consistent with previous research and evaluation methods, the conditions present at the crossing location should be reviewed and the need for the crossing should consider pedestrian traffic volume using the crossing. It is important that the pedestrian use data be collected at multiple times of day to get an accurate picture of the pedestrian traffic need. The highest hour pedestrian need may not coincide with the highest hour traffic volume crossing the location. In such circumstances, the level of service should be evaluated for the highest pedestrian volume hour and the highest vehicle volume hour separately.

If the crossing location is on a roadway with speeds greater than 35 miles per hour (mph), is in a community of less than 10,000 people, or provides a connection to a major transit stop, there should be a minimum of 14 pedestrians using the crossing during one hour of the day.

If the crossing location is on a roadway with a speed of 35 mph or less, there should be a minimum of 20 pedestrians using the crossing during one hour of the day.

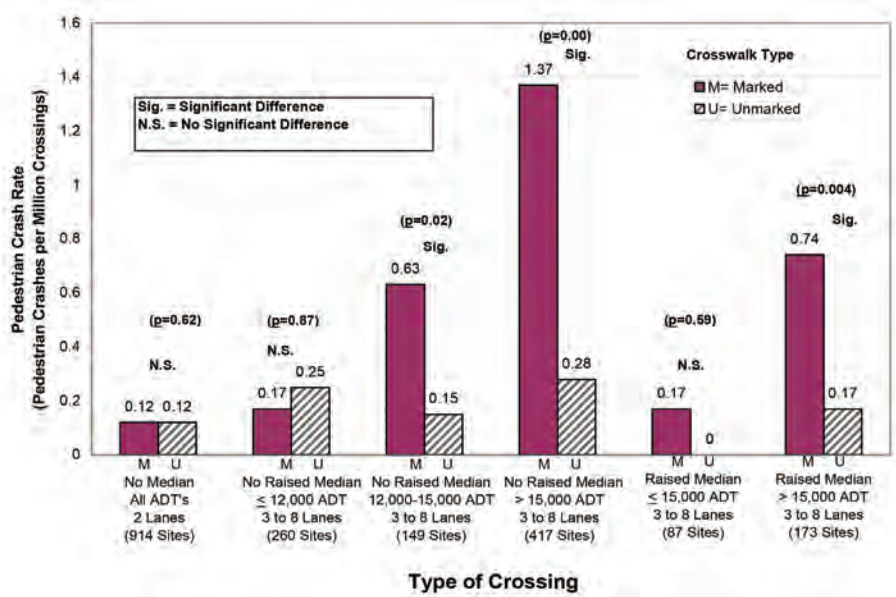
The above pedestrian volume thresholds can be reduced by 0.33 if more than 50 percent of the pedestrian traffic using the crossing consists of the elderly or children.

If these thresholds cannot be met, traffic calming treatments should be considered. In such cases, additional uncontrolled crossing treatments may be considered in conjunction with the traffic calming treatments. Uncontrolled crossing treatments should not be considered by themselves.

STEP 9 FHWA Safety Guidance

Federal Highway Administration (FHWA) guidance in the Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations should be determined based on the traffic volume, speed, and roadway type. The study indicates the types of treatments recommended for installing marked crosswalks at uncontrolled locations.

Research indicates that there is a statistically significant difference in the safety between a marked and unmarked crossing when traffic volume is over 15,000, or over 12,000 without a median, under most speeds, as shown in the table below.



This research provides the basis for the guidance in Table 1 on page 18. Guidelines provided in the table include intersections and midblock locations with no traffic signals or stop signs on the approach to the crossing.

Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians—such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers—without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians.

Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions, etc.) as needed to improve the safety of the crossing.

Guidelines outlined in the table are general recommendations; good engineering judgment should be used in individual cases when deciding where to install crosswalks.

Sources:
C. V. Zeeger, J. R. Stewart, H. H. Huang, P. A. Lagerwey, J. Feaganes and B. Campbell, "Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guide lines," Federal Highway Administration, McLean, VA, September 2005.
K. Fitzpatrick, S. Turner, M. Brewer, P. Carlson, B. Ullman, N. Trout, E. S. Park and J. Whitcare, "Improving Pedestrian Safety at Unsignalized Crossings," Transportation Research Board of the National Academies, Washington, DC, 2006.

Table 1: FHWA Safety Guidance Table

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT ≤ 9,000			Vehicle ADT > 9,000–12,000			Vehicle ADT > 12,000–15,000			Vehicle ADT > 15,000		
	Speed Limit*											
	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)	≤ 48.3 km/h (30 mph)	56.4 km/h (35 mph)	64.4 km/h (40 mph)
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median**	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without raised median	C	P	N	P	P	N	N	N	N	N	N	N

*Where the speed limit exceeds 64.4 km/h (40 mph), marked crosswalks alone should not be used at unsignalized locations.

**The raised median or crossing island must me at least 1.2 meters (4 feet) wide and 1.8 meters (6 feet) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and Amerian Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites. It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or child pedestrians) be confirmed at a location before placing a high priority on the installation of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvements, to improve crossing safety for pedestrians.

STEP 10

School Crossings

The safety of children as they get to and from school is of special consideration and may require the implementation of a crosswalk at locations that might otherwise not be considered. A school crossing location will traditionally have significant use by children that occurs in conjunction with standard school start and dismissal times, making the crossing use noticeable to motorists. Consider appropriate uncontrolled treatment options, including crosswalk markings, signs, and crossing guards.


MARKED AND SIGNED SCHOOL CROSSING

ADULT SCHOOL CROSSING GUARD

STEP 11

Consider Appropriate Treatment Options

Appropriate treatment options should be considered for crossing locations based on the evaluation flowchart on pages 6–7. In many cases, the most appropriate option is to keep the location unmarked and unsigned, as any treatment may increase the crash potential at the location.

The treatment options have been organized into four separate categories depending on their primary function in serving pedestrian crossings. Some of the options have not been shown to noticeably affect motorist yielding and service levels, but they are provided as examples that have been implemented by some agencies.

SIGNING AND MARKING TREATMENTS

Signing and marking treatments are generally low cost and provide little to no benefit in terms of operational impacts. The most significant impact is for high-visibility markings. The treatments can be appropriate by themselves on low-volume and low-speed roadways unless accompanied by other types of treatments.

Potential signing and marking treatments are outlined in Table 2 on page 21 (treatments should be justified through an engineering study). Examples of selected treatments are also shown at right.


CROSSING WARNING SIGN


CROSSWALK MARKINGS AND SIGN

IN-STREET CROSSING SIGN


HIGH-VISIBILITY CROSSWALK MARKINGS

Sources:
"Minnesota's Best Practices for Pedestrian/Bicycle Safety," MnDOT Office of Traffic, Safety and Technology, September 2013.
"Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments," Minnesota Department of Transportation, St.Paul, MN, September 2013.
NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.
Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.
Bolton & Menk, Inc.
Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.
Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

Table 2: Signing and Marking Treatments

Treatment	Advantages	Disadvantages	Recommended Locations	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate	Cost
Crosswalk Markings Only	• Inexpensive • Helps define a crossing location • Indicates to drivers that crossing location is present	• Very little effect at night • Speeds increase over time • Not shown to reduce crashes	• Not usually recommended alone • Low-volume and low-speed road-ways • Where justified	NR	NR	\$500–\$2,000
Warning Signs	• Inexpensive • Helps define a crossing location • Warning to drivers that crossing location is present	• Tend to be ignored unless pedestrians use the crossing consistently • Proven to be ineffective at reducing crashes at uncontrolled intersections	• Where unexpected entries into the road by pedestrians may occur • At or before the crossing location • With or without a marked crosswalk	NR	NR	\$300–\$1,200
Overhead Warning Signs	• May decrease vehicle speed	• Requires overhead structure • Tend to be ignored unless pedestrians use the crossing consistently	• Multilane roadways • Mid-block crossing locations • Usually coupled with other measures such as RRFBs or beacons	NR	NR	\$60,000–\$75,000
Colored Concrete/Brick Pavers	• Inexpensive • Warning to drivers that crossing location is present • May decrease vehicle speed	• Can be expensive • Not shown to reduce crashes	• Downtown/urban conditions • Traffic signal locations • In conjunction with pavement markings	NR	NR	\$10,000–\$75,000
Crosswalk Markings and Signs	• Inexpensive • Warning to drivers that crossing location is present • May decrease vehicle speed	• Make snow removal more difficult • Need consistent maintenance and replacement due to vehicle hits	• Where justified	7%	7%	\$800–\$3,200
In-Street Crossing Signs (25–30 mph)	• Inexpensive • Additional warning to drivers that crossing location is present	• Not shown to reduce crashes • Speeds increase over time	• Downtown/urban conditions • Supplement warning signs at high pedestrian volume locations • In conjunction with pavement markings	87%	90%	\$500–\$1,000
High-Visibility Crosswalk Markings	• May decrease vehicle speed	• Not shown to reduce crashes • Speeds increase over time	• Where justified • Urban conditions	61% (25mph) 17% (35mph)	91% (25mph) 20% (35mph)	\$5,000–\$50,000

NR = No research found on effect to yielding rate

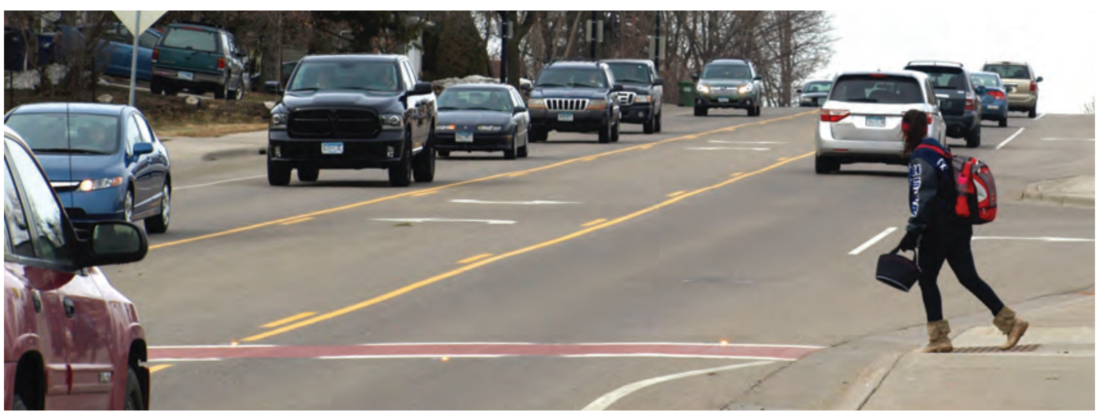
UNCONTROLLED CROSSING TREATMENTS

Uncontrolled crossing treatments generally provide some level of increased yielding rate. They are typically applied to locations with marked crosswalks to provide additional operational and safety benefits in areas with higher volumes and speeds.

Uncontrolled crossing treatement options are outlined in Table 3 on page 23 (treatments should be justified through an engineering study) . Selected treatment examples are also shown below.

OVERHEAD FLASHING SIGNAL BEACONS


CENTER MEDIAN WITH REFUGE ISLAND


IN-ROAD WARNING LIGHTS

PEDESTAL-MOUNTED FLASHING SIGNAL BEACONS


RAPID RECTANGULAR FLASHING BEACONS

Table 3: Uncontrolled Crossing Treatments (in conjunction with markings and signs)

Treatment	Advantages	Disadvantages	Recommended Locations	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate	Cost
Center Median with Refuge Island	• Decreases pedestrian crossing distance • Provides higher pedestrian visibility • Reduces vehicle speeds approaching the island • Reduces conflicts • Increases usable gaps • Reduces pedestrian exposure time	• May make snow removal more difficult • May be a hazard for motorists • Small islands not recommended on high-speed roadways (>40 mph)	• Wide, two-lane roads and multilane roads with sufficient right-of-way	34%	29%	Variable depending on length
School Crossing Guards	• Inexpensive • Provides higher pedestrian visibility • Highlights when a pedestrian crossing is being used	• May require trained staff or local law enforcement, especially on high-speed and high-volume roadways	• At school locations	NR	86%	Variable
Pedestrian Crossing Flags	• Inexpensive • Provides higher pedestrian visibility to drivers assuming the flag is held in a noticeable location	• No effect at night • Requires pedestrians to actively use a flag • Can be easily removed/stolen • Shorter crossings are preferred	• Downtown/urban locations • High pedestrian volume locations • Across low-speed (<45mph) roadways	65%	74%	<$500
Warning Sign with Edge Mounted LEDs	• Highlights a crossing both at night and during the day	• Requires pedestrian activation • Minimal to no effect on speed	• In conjunction with in-road warning lights • Downtown/urban conditions	NR	28%	$3,000–$8,000
In-Road Warning Lights	• Highlights a crossing both at night and during the day • Provides higher driver awareness when a pedestrian is present	• Snowplows can cause maintenance issues • No effect when road surface is snow covered • Requires pedestrian activation	• Downtown/urban conditions	NR	66%	$20,000–$40,000
Pedestal Mounted Pedestrian Flashing Signal Beacons	• Provides higher driver awareness when a pedestrian is present	• Requires pedestrian activation • Not advisable on multilane streets • Not shown to reduce crashes	• Low-speed school crossings • Two-lane roads • Midblock crossing locations	NR	57% (two-lane, 35mph)	$12,000–$18,000
Pedestrian Overhead Flashing Signal Beacons	• Provides higher driver awareness when a pedestrian is present	• Requires pedestrian activation	• Multilane roadways • Mid-block crossing locations • Lower speed roadways	active 47% passive 31%	active 49% passive 67%	$75,000–$150,000
Rectangular Rapid Flash Beacons (RRFBs)	• Provides higher driver awareness when a pedestrian is present • Increases yielding percentage • Increases usable gaps • Reduces probability of pedestrian risk taking • Can be seen from 360 degrees	• Requires pedestrian activation	• Supplement existing pedestrian crossing warning signs • School crossings • Midblock crossing locations • Low- and high-speed roadways	84%	81%	$12,000–$18,000

NR = No research found on effect to yielding rate

TRAFFIC CALMING TREATMENTS

Traffic calming treatments are generally applied to locations experiencing high traffic speeds. Traffic speeds should be lowered to enable any type of at-grade crossing. Traffic calming treatments can also be used to shorten crossing distances and improve pedestrian visibility. The shortened crossing distances reduce the total time of exposure to conflicting traffic, resulting in safer crossing environments. These treatments may be completed in conjunction with other uncontrolled crossing treatments.

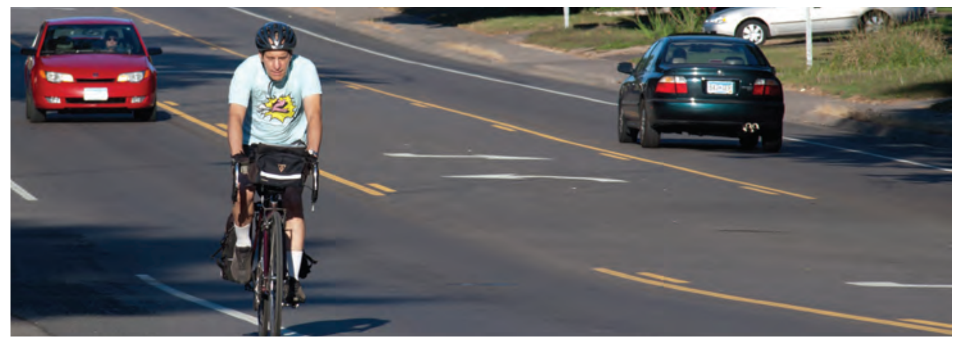
A variety of traffic calming treatments are outlined in Table 4 on page 25 (treatments should be justified with an engineering study). Examples of selected treatment options are also shown at right.

For more information on traffic calming treatment options, please see these resources (in addition to the sources listed below):

- LRRB Report MN/RC-1999-01, Effective Traffic Calming Applications and Implementation;
- TRS 0801, Traffic Calming for High Speed Rural Highways
- LRRB Report 2013-31, Implications of Modifying State Aid Standards: Urban Construction or Reconstruction to Accommodate Various Roadway Users
- http://mndot.gov/planning/completestreets

CURB BUMP-OUTS

CHANNELIZED TURN LANE WITH RAISED CROSSING



ROAD DIET/4-LANE TO 3-LANE CONVERSION

CENTER MEDIAN WITH REFUGE ISLAND

Sources:
"Minnesota's Best Practices for Pedestrian/Bicycle Safety," MnDOT Office of Traffic, Safety and Technology, September 2013.
"Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments," Minnesota Department of Transportation, St.Paul, MN, September 2013.
NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.
Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011. Bolton & Menk, Inc.
Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.
Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

Table 4: Traffic Calming Treatments

Treatment	Advantages	Disadvantages	Recommended Locations	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate	Cost
Center Median with Refuge Island	• Decreases pedestrian crossing distance • Provides higher pedestrian visibility • Reduces vehicle speeds approaching the island • Reduces conflicts • Increases usable gaps • Reduces pedestrian exposure time	• May make snow removal more difficult • May be a hazard for motorists • Small islands not recommended on high-speed roadways (>40 mph)	• Wide, two-lane roads and multilane roads with sufficient right-of-way	34%	29%	Variable depending on length
Raised Crossings	• Provides higher pedestrian visibility to vehicles • Can reduce vehicle speeds	• Make snow removal more difficult • May reduce emergency vehicle response times • Only appropriate in low-speed/urban environments	• Low-speed/urban environments	NR	NR	$5,000–$25,000
Lighting	• Can be inexpensive • Can reduce vehicle speeds	• No effect during daylight	• Targeted crossing locations not located on a street with continuous roadway lighting	NR	NR	$1,000–$40,000
Pavement Striping (Road Diet)	• Can be inexpensive • May decrease vehicle speed • May decrease illegal right-side passing • Can be an interim solution	• Does not provide a physical barrier between modes • Pedestrian crossing distance same as existing	• Four-lane undivided roadways • Locations with very long crossings	NR	NR	Variable depending on length
Curb Bump-Outs/ Extensions	• Can be inexpensive • Reduces pedestrian crossing distance • Provides higher pedestrian visibility to vehicles • Reduces speed for turning vehicles • Decreases in illegal right-side passing	• May make snow removal more difficult • Proximity of curb to through traffic may be a safety concern	• Downtown/urban locations	NR	NR	$5,000–$15,000 per crossing
Channelized Turn Lanes (Corner Islands) *(Not usually recommended as a pedestrian crossing treatment)*	• Decreases pedestrian crossing distance • Provides higher pedestrian visibility • Decrease in illegal right-side passing	• May require new pavement • Can be more challenging for visually impaired pedestrians • Right turning drivers often fail to yield to pedestrians • Can increase right-turn vehicle speeds • May make snow removal more difficult • Vehicle crashes may increase	• Intersections with wide approaches • Intersections with right turn lanes and sufficient corner right-of-way • Intersections with operational improvment needs	NR	NR	$50,000–$100,000 per intersection

NR = No research found on effect to yielding rate

HIGH-LEVEL TREATMENTS

High-level treatments are high cost and are generally implemented on high-volume and high-speed roadways. They are much more difficult to implement unless they are justified based on traffic and pedestrian volume.

Possible high-level treatments are outlined in Table 5 on page 27, and examples of selected treatment options are shown below. For additional information on Treatment Options, please see the sources listed below.

PEDESTRIAN HYBRID BEACON


TRAFFIC SIGNAL


UNDERPASS


OVERPASS

REPEAT STEP 4

Evaluate LOS for Treatment Options

Step 4 should be repeated after deciding on a treatment option. Determine the level of service (LOS) of the crossing condition with the potential treatment options following the procedure as outlined in the 2010 *Highway Capacity Manual*. An acceptable service level should be determined by the agency.

If acceptable service levels cannot be met:

- Do nothing (consider leaving the crossing unmarked and unsigned),
- Consider pedestrian routing to another location, and/or
- Consider appropriate high-level treatments.

Sources:
"Minnesota's Best Practices for Pedestrian/Bicycle Safety," MnDOT Office of Traffic, Safety and Technology, September 2013.
"Best Practices Synthesis and Guidance in At-Grade Trail-Crossing Treatments," Minnesota Department of Transportation, St.Paul, MN, September 2013.
NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.
Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.
Bolton & Menk, Inc.
Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.
Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

Table 5: High-Level Treatments

	• Provides higher driver awareness when a pedestrian is present • Has been shown to decrease pedestrian crashes	• Potential increase in vehicle crashes • Can have spotty compliance rates due to a lack of driver understanding	• Justified locations • Mid-block crossing locations	97%	99%	$150,000–$300,000
	• Provides higher driver awareness when a pedestrian is present • Easily understandable	• May increase crashes due to the driver expectation of a green signal indication	• High pedestrian volume crossings • Justified locations, meets signal warrants	NA	NA	$150,000–$300,000
	• Removes pedestrian/vehicle conflicts	• Potential of the crossing not being used • Very location specific • Very expensive • Drainage within an underpass can be problematic • Underpass would require lighting	• Location with compatible grades • High pedestrian volume crossings • High-volume roadways • High-speed roadways	NA	NA	$800,000+
	• Removes pedestrian/vehicle conflicts	• Potential of the crossing not being used • Very location specific • Very expensive • Snow removal on overpass may be difficult	• Location with compatible grades • High pedestrian volume crossings • High-volume roadways • High-speed roadways	NA	NA	$1,200,000+

NA = Not applicable or no research found on effect to yielding rates

Uncontrolled Pedestrian Crossing
Data Collection Worksheet

LRRB

Location: ______________________ Date: ______________________

City, State: ______________________ Scenario: ______________________

Reviewer(s): ______________________ Agency: ______________________

Project #: ______________________ ID #: ______________________

The first step in understanding the pedestrian needs at a potential crossing location is completing a review of the location and adjacent facilities.

Geometrics

Crossing Length: Measure the crossing distance from curb to curb. Fill in Crossing 1 distance if there is no median. If there is a median at the crossing location, fill in Crossing 1 and 2 distances.
- Crossing 1 ____ ft.
- Crossing 2 ____ ft.

Median: width of median at crossing location ____ ft.

Crossing Width: effective crosswalk width ____ ft.

Raised Median Available? ☐ Yes ☐ No

ADA Compliant Median Available (minimum 4' x 4' landing)? ☐ Yes ☐ No

Curb Ramps Available? ☐ Yes ☐ No

ADA Compliant Curb Ramp Available (width, grades, truncated domes)? ☐ Yes ☐ No

Speed: Posted or 85th percentile speed ____ mph

Roadway Curvature and Sight Distances: Average walking speed ____ ft/s

Is the crossing location within a horizontal or vertical curve? ☐ Yes ☐ No

Equations to calculate the following are located on the next page

Direction 1:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Stopping Sight Distance (SSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 1:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No
Direction 2:	Pedestrian Sight Distance (PedSD)	____ ft.	provided?	☐ Yes	☐ No

Traffic and Pedestrian Data

Measure traffic and pedestrian volume in 15-minute increments on the roadway to be crossed.

Attach Counts	**vehicles:**		Daily	**pedestrians:**		Daily
AM Peak	Hourly		Pk 15-min	Hourly		Pk 15-min
PM Peak	Hourly		Pk 15-min	Hourly		Pk 15-min

Additional Site Characteristics

Lighting:

Is street lighting present and does it light the crosswalk location? ☐ Yes ☐ No

Crosswalk Pavement Markings: Is the pedestrian crossing currently marked? ☐ Yes ☐ No

What is the condition of the markings? ☐ Excellent ☐ Good ☐ Fair ☐ Poor

Are the markings easily defined? ☐ Yes ☐ No

Do they need replacement? ☐ Yes ☐ No

What is the crosswalk marking pattern? ____________

Signing: Currently signed at crosswalk? ☐ Yes ☐ No

Currently signed in advance of crosswalk? ☐ Yes ☐ No

Distances? direction 1 ____ ft. direction 2 ____ ft.

Enhancements: What enhancements are currently at the crossing location? ____________

Adjacent Facilities: Distance to nearest marked crosswalk? ____ ft.

What pedestrian control devices are present at the nearest adjacent marked crosswalk? ____________

Distance to nearest all-way stop, roundabout or signalized intersection ____ ft.

Could another location serve the same pedestrian crossing movement? ☐ Yes ☐ No

Could another location serve the the movement more effectively? ☐ Yes ☐ No

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Uncontrolled Pedestrian Crossing
Data Collection Worksheet

Mark the following: site distances and potential conflicts, pavement markings (crosswalk, edge lines, center lines, lane lines, stop lines, and any other markings), signing, location of lighting units, curb ramps, truncated domes, presence of any other crosswalks or crossing locations parallel to and nearby the location being studied, adjacent intersection traffic control, parking, intersection width, lane lengths, shoulder widths, sign placement, and nearby orgins and destinations .

draw or insert map of location being studied

Notes: ______________________________

____

____

____

____

Sight Distance Calculations:

Stopping sight distance (SSD), ft = $1.47St + 1.075S^2/a$

Pedestrian sight distance (PedSD), ft = $1.47S(L / S_p + t_s)$

where: S = design speed, mph

L = length of crossing, ft

where:	defaults:
t = brake reaction time, s	2.5
a = deceleration rate, ft/s^2	11.2
S_p = average pedestrian walking speed, ft/s	3.5
t_s = pedestrian start-up and end clearance time, s	3.0

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations
Intersection and Mid-Block Crossings

Introduction:

The Worksheets provide a procedure for evaluating the Level of Service (LOS) at uncontrolled pedestrian crossings according to the methodology presented in Chapter 19 of the 2010 Highway Capacity Manual. Uncontrolled pedestrian crossings include: marked crossings at mid-block locations; marked crossings at intersections; and unmarked crossings at intersections, that are not controlled by a traffic control device such as signals and stop or yield signs.

Use of these Worksheets in Microsoft Excel results in an automated procedure. While this automated procedure has been checked for accuracy using multiple examples, no warranty is made by the developers as to the accuracy, completeness, or reliability of the equations and results. No responsibility is assumed for incorrect results or damages resulting from the use of these worksheets.

This process is not for use at signalized crossings and has not been verified to be accurate for unsignalized pedestrian crossings within a signalized corridor.

The equations and methodology presented through this process is contained within the 2010 Highway Capacity Manual (HCM). Any questions on the approach, assumptions, and limitations of the procedure or for verification of equations are directed to the 2010 HCM.

This material was developed by Bolton & Menk, Inc. in coordination with the Local Road Research Board (LRRB) for the use by practicioners. These Worksheets are made without charge and under no circumstances shall be sold by third parties for profit.

Submitted for Approval: May 12, 2014
Updated June 6, 2014

2010 Highway Capacity Manual (HCM)

Pedestrian Level of Service (LOS) at Uncontrolled Crossing Locations
Intersection and Mid-Block Crossings

Crossing Location:	______	Date:	______
City, State:	______	Scenario:	______
Reviewer(s):	______	Agency:	______
Project Number:	______	ID #:	______

The following is the base information needed to complete the analysis.
If this is a one-stage crossing, use only Crossing 1.
If this is a two-stage crossing, each stage must be evaluated separately using Crossing 1 and Crossing 2.

Crossing 1: ______

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing 2: ______ (only used for two-stage crossings)

Evaluation Inputs:	defaults:		Input Table:	
L = crosswalk length (ft)			L =	
S_p = average pedestrian walking speed (ft/s)	S_p =	3.5	S_p =	
t_s = pedestrian start-up and end clearance time (s)	t_s =	3.0	t_s =	
V = vehicular hourly volume (veh/hr)			V =	
v_p = pedestrian flow rate (ped/s)	v_p =	0*	v_p =	
v = vehicular flow rate (veh/s) = V/3600	v =	V/3600	v =	
W_c = crosswalk width (ft)	W_c =	8.0	W_c =	
N = number of through lanes crossed (Integer)	N =	INT(L/11)	N =	

*no platooning observed

Crossing Treatment Yield Rate

	Input Table:	
M_y = motorist yield rate (decimal)	M_y =	

Entering data into the tables above will populate the evaluation tables in Microsoft Excel.

Results:

Average Delay		sec/ped
LOS		

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

LRRB

Crossing Location: ______ Date: ______
City, State: ______ Scenario: ______
Reviewer(s): ______ Agency: ______

Step 1: Identify Two-Stage Crossings

Is there a median available for a two-stage crossing? ☐ Yes ☐ No
If yes, does the median refuge meet ADA requirements (4' x 4' landing)? ☐ Yes ☐ No
If yes, do pedestrians treat this as a two-stage crossing location? ☐ Yes ☐ No

Step 2: Determine Critical Headway

Critical headway is the time below which a pedestrian will not attempt to begin crossing the street. Pedestrians use judgement to determine whether the available headway is sufficent for a safe crossing.

For a single pedestrian:

$$t_c = \frac{L}{S_p} + t_s$$

where: t_c = critical headway for a single pedestrian (s)
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s)
t_s = pedestrian start-up and end clearance time (s)

crossing 1		crossing 2	
L =	t_s =	L =	t_s =
S_p =	t_c =	S_p =	t_c =

S_p = 3.5 ft/s
t_s = 3 sec

If pedestrian platooning is observed, the spatial distribution of pedestrians should be computed:

1. use field observations or estimate platoon size using equation:

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$$

where: N_c = total number of pedestrians in crossing platoon (ped)
v_p = pedestrian flow rate (ped/s)
v = vehicular flow rate across crossing (veh/s)
t_c = single pedestrian critical headway (s)

crossing 1		crossing 2	
v_p =	t_c =	v_p =	t_c =
v =	N_c =	v =	N_c =

2. compute spatial distribution:

$$N_p = INT\left[\frac{8.0(N_c - 1)}{W_c}\right]$$

where: N_p = spatial distributions of pedestrians (ped)
N_c = total number of pedestrians in crossing platoon (ped)
W_c = crosswalk width (ft)
8.0 = default clear width used by a single pedestrian to avoid interference with other pedestrians (ft)

crossing 1		crossing 2	
N_c =		N_c =	
W_c =	N_p =	W_c =	N_p =

clear width, if other than 8: ______ ft.

3. compute group critical headway:

$$t_{c,G} = t_c + 2(N_p - 1)$$

where: $t_{c,G}$ = group critical headway (s)
t_c = single pedestrian critical headway (s)
N_p = spatial distributions of pedestrians (ped)

crossing 1		crossing 2	
N_p =		N_p =	
t_c =	$t_{c,G}$ =	t_c =	$t_{c,G}$ =

Step 3: Estimate Probability of a Delayed Crossing

Probability that a pedestrian will not incur any crossing delay is equal to the likelihood that a pedestrian will encounter a gap greater than or equal to the critical headway immediately upon arrival at the intersection.

$$P_b = 1 - e^{\frac{-t_{c,G} v}{L}}$$

$$P_d = 1 - (1 - P_b)^L$$

where: P_b = probability of blocked lane
P_d = probability of delayed crossing
N = number of through lanes crossed
$t_{c,G}$ = group critical headway (s) = t_c, if no platooning
v = vehicular flow rate across crossing(veh/s)

crossing 1		crossing 2	
$t_{c,G}$ =		$t_{c,G}$ =	
v =	P_b =	v =	P_b =
N =	P_d =	N =	P_d =

LRRB

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Step 4: Calculate Average Delay to Wait for Adequate Gap

Average delay assumes that no motor vehicles yield and the pedestrian is forced to wait for an adequate gap.

$$d_g = \frac{1}{v}\left(e^{vt_{c,G}} - vt_{c,G} - 1\right)$$

where: d_g = average pedestrian gap delay (s)
$t_{c,G}$ = group critical headway (s)
v = vehicular flow rate across crossing (veh/s)

crossing 1		crossing 2	
$t_{c,G}$ =		$t_{c,G}$ =	
v =	d_g =	v =	d_g =

Average delay for a pedestrian who is unable to cross immediately upon reaching the intersection (e.g., any pedestrian experiencing nonzero delay.)

$$d_{gd} = \frac{d_g}{P_d}$$

where: d_{gd} = average gap delay for pedestrians who incur nonzero delay
d_g = average pedestrian gap delay (s)
P_d = probability of a delayed crossing

crossing 1		crossing 2	
d_g =		d_g =	
P_d =	d_{gd} =	P_d =	d_{gd} =

Step 5: Estimate Delay Reduction due to Yielding Vehicles

(If yielding is zero, then skip step 5)

When a pedestrian arrives at a crossing and finds an inadequate gap, that pedestrian is delayed until one of two situations occurs: (a) a gap greater than the critical headway is available, or (b) motor vehicles yield and allow the pedestrian to cross. While motorists are legally required to stop for crossing pedestrians in MN at all intersections and at all marked crossings, motorist yield rates actually vary considerably.

Some crossing treatments and yield rates based on research are provided on the next page.

Average pedestrian delay

$$d_p = \sum_{i=1}^{n} h(i-0.5)\,P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i)\right) d_{gd}$$

where: d_p = average pedestrian delay (s)
i = crossing event (i=1 to n)
h = average headway for each through lane = N/v
$P(Y_i)$ = probability that motorists yield to pedestrian on crossing event i
n = Int(d_{gd}/h), average number of crossing events before an adequate gap is available, >0
j = crossing event (j=0 to i-1)
$P(Y_j)$ = probability that motorists yield to pedestrian on crossing event j

crossing 1		crossing 2	
h =	n =	h =	n =
	d_p =		d_p =

1. One-Lane Crossing

$$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$$

2. Two-Lane Crossing

M_y = motorist yield rate (decimal) M_y =

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{\left(2P_b(1-P_b)M_y\right) + \left(P_b^{\,2}M_y^{\,2}\right)}{P_d}\right]$$

3. Three-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{P_b^{\,3}M_y^{\,3} + 3P_b^{\,2}(1-P_b)M_y^{\,2} + 3P_b(1-P_b)^2 M_y}{P_d}\right]$$

4. Four-Lane Crossing

$$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] \text{x} \left[\frac{P_b^{\,4}M_y^{\,4} + 4P_b^{\,3}(1-P_b)M_y^{\,3} + 6P_b^{\,2}(1-P_b)^2 M_y^{\,2} + 4P_b(1-P_b^{\,3})M_y}{P_d}\right]$$

Summary	
Average	
LOS	

Step 6: Calculate Average Pedestrian Delay & Determine LOS

LOS	Control Delay (sec/ped)	Comments
A	0-5	Usually no conflicting traffic
B	5-10	Occasionally some delay due to conflicting traffic
C	10-20	Delay noticeable to pedestrians, but not inconvienencing
D	20-30	Delay noticeable/irritating, increased chance of risk-taking
E	30-45	Delay approaches tolerance level, risk-taking likely
F	>45	Delay exceeds tolerance level, high chance of risk-taking

Uncontrolled Pedestrian Crossing Level of Service Evaluation Worksheet

Determine if there is a crossing treatment used that could provide vehicle yielding. This then provides a possible reduction in delay.

Motorist Yield Rate = M_y

Crossing Treatment	Staged Pedestrian Yield Rate	Unstaged Pedestrian Yield Rate
Crosswalk Markings and Signs Only [1]	7%	7%
Median Refuge Islands [1]	34%	29%
Pedestal Mounted Flashing Beacon (2-Lane, 35 mph) [3]	N/A	57%
Overhead Flashing Beacon (push-button activation) [1]	47%	49%
Overhead Flashing Beacon (passive activation) [1]	31%	67%
Pedestrian Crossing Flags [1]	65%	74%
School Crossing Guards [5]	N/A	86%
In-street Crossing Signs (25-30 mph) [1]	87%	90%
Warning Sign with Edge Mounted LEDs [6]	N/A	28%
In-road warning lights [1]	N/A	66%
High-visibility Signs and Markings (35 mph) [1]	17%	20%
High-visibility Signs and Markings (25 mph) [1]	61%	91%
Rectangular Rapid-Flash Beacon (RRFB) [2][4]	84%	81%
School Crossing Guards with RRFB [5]	N/A	91%
Pedestrian Hybrid Beacon (HAWK) [1]	97%	99%
	N/A: No Research Found on Effect to Yielding Rate	

Sources:

(1) Fitzpatrick, K., S.M. Turner, M. Brewer, P.J. Carlson, B. Ullman, N.D. Trout, E.S. Park, J. Whitacre, N. Lalani, and D. Lord. NCHRP Report 562: Improving Pedestrian Safety at Unsignalized Crossings. Transportation Research Board of the National Academies, Washington D.C., 2006.

(2) Lewis, R., J.R. Ross, D.S. Serpico : Assessment of Driver Yield Rates Pre- and Post-RRFB Installation, Bend, Oregon. Oregon Department of Transportation, Washington D.C., 2011.

(3) Bolton & Menk Field Data Collection

(4) Transportation Research Board, HCM 2010 Highway Capacity Manual, Washington D.C.: National Academy of Sciences, 2010.

(5) Brewer, Marcus A., Kay Fitzpatrick. Before-and-After Study of the Effectiveness of Rectangular Rapid-Flashing Beacons Used with School Sign in Garland, Texas. Texas Transportation Institute, College Station, TX, April 2012.

(6) Kipp, Wendy M.E., Jennifer M. V. Fitch. Evaluation of SmartStud In-Pavement Crosswalk Lighting System and BlinkerSign Interim Report. Vermont Agency of Transportation, Report 2011-3, Montpelier, VT, February 2011. (Rate Normalized to High Visibility Markings and Signs at 35 mph)