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Nevada Department of Transportation

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Feasibility of Implementing Pedestrian Hybrid Beacon (PHB) Signals for Improving Safety and Mobility in Nevada

May 2024

Disclaimer

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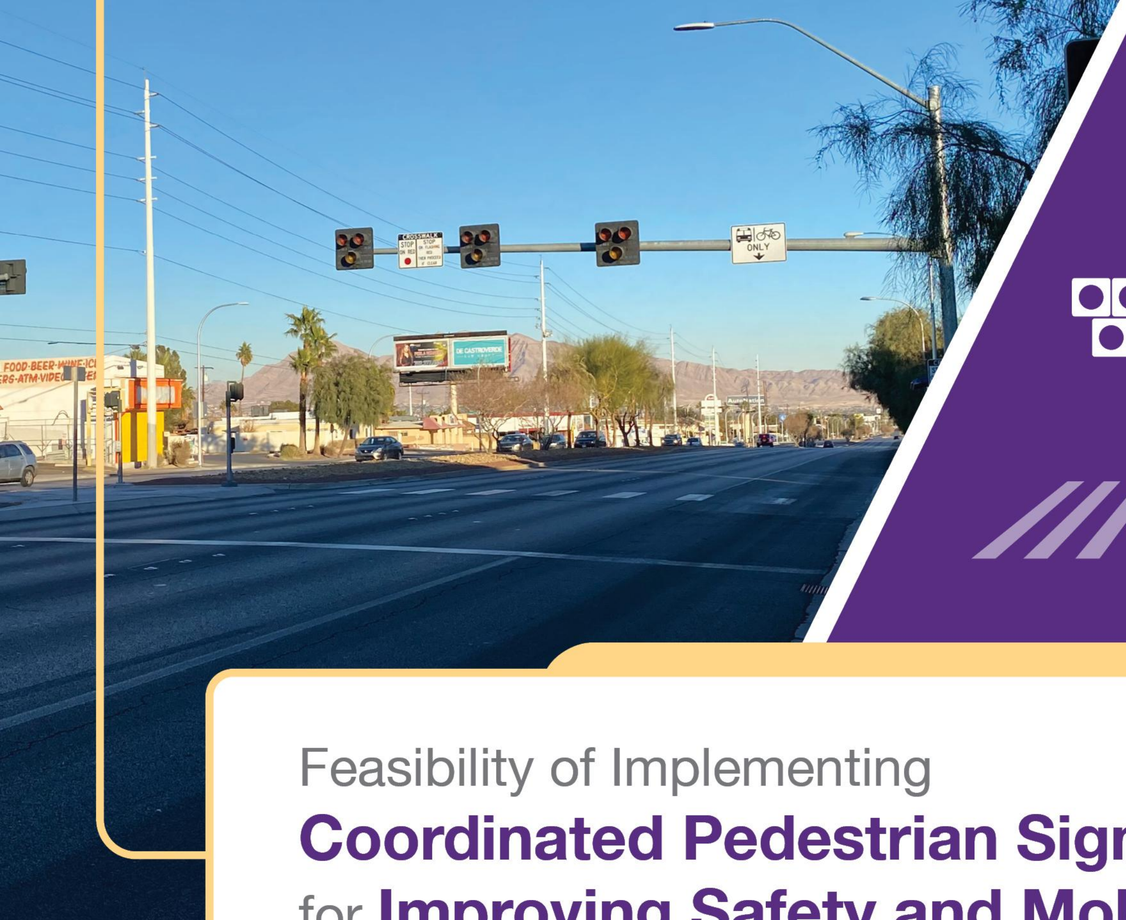

Feasibility of Implementing

Coordinated Pedestrian Signals for Improving Safety and Mobility in Nevada

NEVADA DOT SAFE AND CONNECTED

Kimley»Horn Expect More. Experience Better.

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RESEARCH REPORT

May 2024

RESEARCH REPORT

FOR

FEASIBILITY OF IMPLEMENTING MID-BLOCK PEDESTRIAN SIGNALS FOR IMPROVING SAFETY AND MOBILITY IN NEVADA

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ABBREVIATIONS, ACRONYMS, AND GLOSSARY

ADT	Average Daily Traffic
Belisha	Large-diameter post-mounted amber beacon used at British pedestrian crossings, first implemented in 1934 by Leslie Hore-Belisha
B/C	Benefit/Cost
CAMPO	Carson Area Metropolitan Planning Organization
CMF	Crash Modification Factor
DfT	Department for Transport (of the United Kingdom)
EAB	Enhanced Amber Beacon
FARS	Fatalities Analysis Reporting System
FHWA	Federal Highway Administration
FDW	Flashing Don't Walk (signal)
FR	Flashing Red (signal)
FY	Flashing Yellow (signal)
GIS	Geographic Information System
GS	Grade Separation
HAWK	Obsolete term for a pedestrian hybrid beacon (*h*igh-intensity *a*ctivated cross*w*al*k*)
IRR	Internal Rate of (economic) Return
MBS	Mid-Block Signal
MTO	Ministry of Transportation of Ontario (Canada)
MUTCD	Manual on Uniform Traffic Control Devices
NCATS	Nevada Citation and Accident Tracking System
NDOT	Nevada Department of Transportation
NHP	Nevada Highway Patrol
NPV	Net Present (economic) Value
PHB	Pedestrian Hybrid Beacon
Pelican	Older British design for a three-color mid-block pedestrian crossing (originally PELICON, *pe*destrian *li*ght *con*trolled)
Puffin	Newer British design for a three-color mid-block pedestrian crossing
REMSA	Regional Emergency Medical Services Authority
RRFB	Rectangular Rapid-Flashing Beacon
RTC	Regional Transportation Commission

SR	Steady Red (signal)
SY	Steady Yellow (signal)
Synchro	Brand name of a commercial traffic signal optimization software package
TAC	Technical Advisory Committee
Vissim	Brand name of a commercial traffic simulation software package
Zebra	European term for a marked pedestrian crossing (so called due to the pavement marking pattern)

1. EXECUTIVE SUMMARY

Pedestrian safety has been a major concern throughout the 140-year history of the automobile, resulting in the development of numerous safety treatment options for mid-block pedestrian crossings. These include several types of beacons and signals. Some of these devices use flashing yellow beacons to alert motorists to pedestrian presence, while others include a red light to make it mandatory for motorists to stop and allow pedestrians to cross. Most of these electrical devices can be augmented with physical features such as raised crosswalks that force vehicles to slow as they approach the crossing, or mid-block pedestrian refuge islands that allow pedestrians to cross wide streets in two stages.

In Nevada as throughout the United States, inconsistent device selection has resulted in undertreatment at some pedestrian crossings and overtreatment at others. This report summarizes the project team's research and recommendations on methods for selecting appropriate treatments based on local site conditions. Much of this work is encapsulated in a Microsoft Excel workbook intended to assist practitioners with identifying the most cost-effective treatment type based on expected pedestrian safety benefits.

In addition, this report explores the effects of Rectangular Rapid-Flashing Beacons (RRFBs) and Pedestrian Hybrid Beacons (PHBs) on pedestrian and motorist delays under various signal timing strategies for the high-volume conditions typical of major arterials in the greater Las Vegas area. The report's appendices include a detailed literature review and other supporting documentation.

1.1. Nevada Pedestrian Safety

From 2015-2019, Nevada averaged 73.6 pedestrian fatalities per year, a per capita pedestrian death rate 36% above the national average. In addition, according to medical data compiled by the US Centers for Disease Control & Prevention (CDC), each year about 625 Nevada pedestrians required hospitalization after being struck by a motor vehicle, and more than 1500 were treated and released at emergency departments. When all costs are considered, these crashes resulted in losses incurred by insurers, taxpayer-funded healthcare programs, employers, pedestrians, and families totaling well over $1 billion per year. More than a third of vehicle-pedestrian crashes occurred when pedestrians were crossing urban, suburban, or small-town streets at mid-block locations.

Many urban and suburban roadways in Nevada are wide and straight, with long distances between intersections and high travel speeds. When pedestrians must cross multiple lanes, vehicles that have already stopped for the pedestrian can block the view for drivers approaching in adjacent lanes as shown in **Figure 1**. Safely crossing these roadways can be difficult for pedestrians, with notable risks for children, elderly people, and people with disabilities. In fact, pedestrians account for nearly 25% of all Nevada fatalities and 15% of serious injuries, with about 90% of these fatalities occurring in Clark and Washoe Counties. Although these fatalities and serious injuries take place in a variety of settings, one notable point of vulnerability is crossings of urban and suburban arterials.

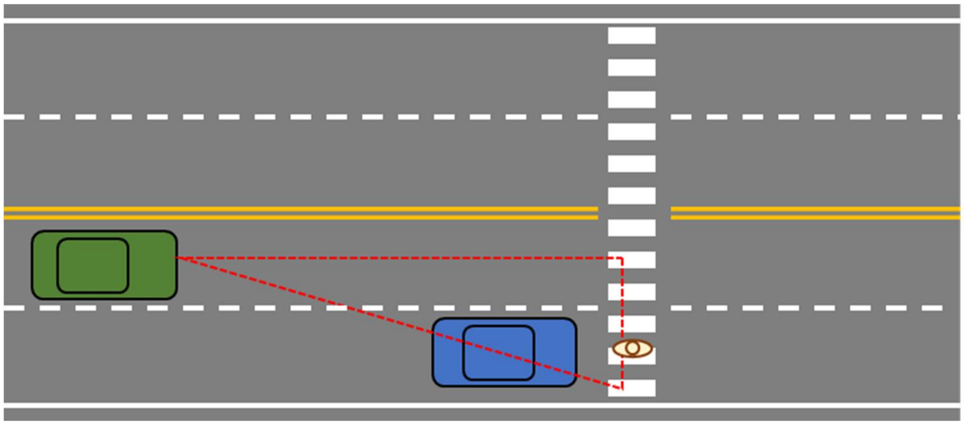


Figure 1 – Presence of a Stopped Vehicle Obstructing Pedestrian Visibility for Vehicles in Adjacent Lanes

1.2. Treatment Options

As shown in **Figure 2** the available mid-block pedestrian crossing treatment options can be organized hierarchically into six main categories: no treatment, unsignalized crosswalks, RRFBs, enhanced amber beacons (EABs), pedestrian hybrid beacons (PHBs), three-color mid-block signals (MBS), and grade separations (GS).

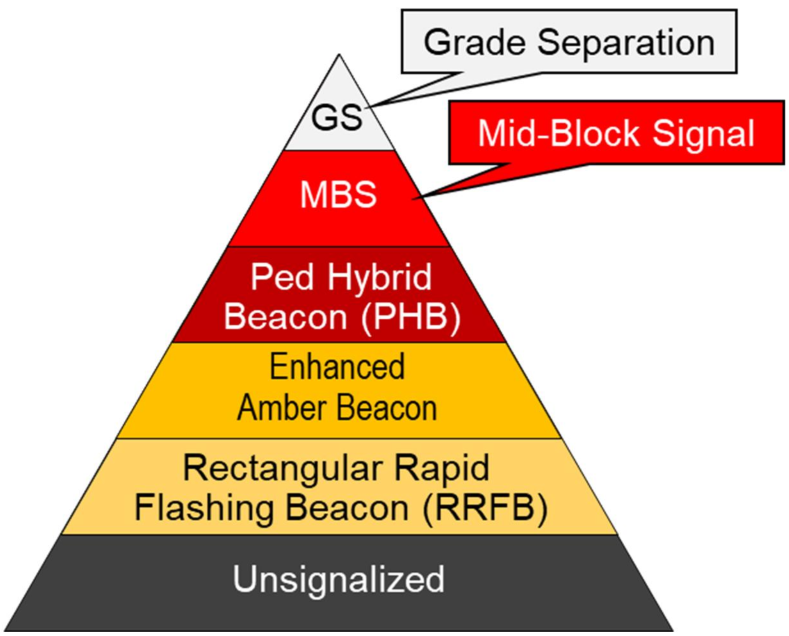


Figure 2 – Recommended Pedestrian Crossing Treatment Hierarchy

Each treatment provides a different combination of physical characteristics, operational requirements, safety performance, installation costs, and maintenance requirements. Briefly, the options are as follows:

Level 0: No treatment. With no delineated pedestrian crossing location, pedestrians can potentially cross anywhere along the roadway frontage (**Figure 3**). As a result, pedestrian trajectory is often somewhat diagonal to the traffic lanes. When crashes occur, they are often widely dispersed along the roadway segment, making it difficult to identify trouble spots through crash mapping.

Photo: Brett VA/Wikimedia Commons

Figure 3 – Level 0: Unmarked Pedestrian Crossing in DuPont, WA

Level 1: Unsignalized marked pedestrian crossing. This type of crossing is delineated by signs and pavement markings (**Figure 4**). Some sites have overhead illumination, but in US practice there are no warning beacons or signals. In the international literature this is referred to as a zebra crossing.

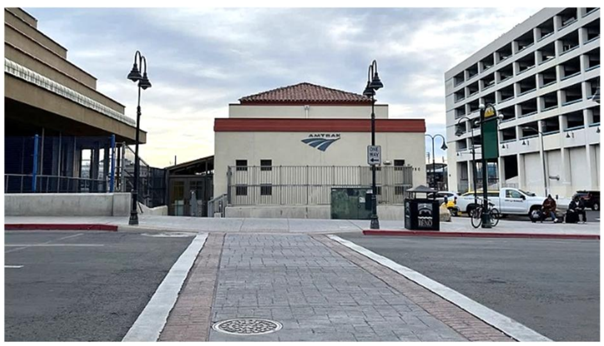


Photo: Missvain/Wikimedia Commons CC 4.0

Figure 4 – Level 1: Unsignalized Pedestrian Crossing in Reno, NV

Level 2: Rectangular rapid-flashing beacon (RRFB). This type of crossing has signs, pavement markings, and pairs of post-mounted (or sometimes overhead-mounted) amber beacons that flash an in a wig-wag pattern for several seconds after activation by a pedestrian (**Figure 5** and **Figure 6**). **Section 9.4** provides guidance on the computation of this interval.

Image: Michael Frederick/pedbikeimages.org [open source]

Figure 5 – Level 2: Rectangular Rapid-Flashing Beacons (RRFBs) Mounted on Posts, St. Petersburg, FL

Image: Google Earth

Figure 6 – Level 2: Rectangular Rapid-Flashing Beacons (RRFBs) Mounted on a Mast Arm, Martin Luther King Boulevard, West Las Vegas, NV

Level 3: Enhanced pedestrian-activated amber beacon (EAB). This type of crossing is similar to an RRFB but includes both post-mounted and overhead-mounted full-size circular amber beacons, which flash for several seconds after activation by a pedestrian (**Figure 7** and **Figure 8**) for enhanced visibility. The crossing also includes signs and pavement markings. **Section 7.2** provides additional detail on the differences between RRFBs and EABs and **Section 9.4** provides guidance setting the flashing amber duration.

Photo: City of Long Beach, CA

Figure 7 – Level 3: Enhanced Amber Beacon in Long Beach, CA

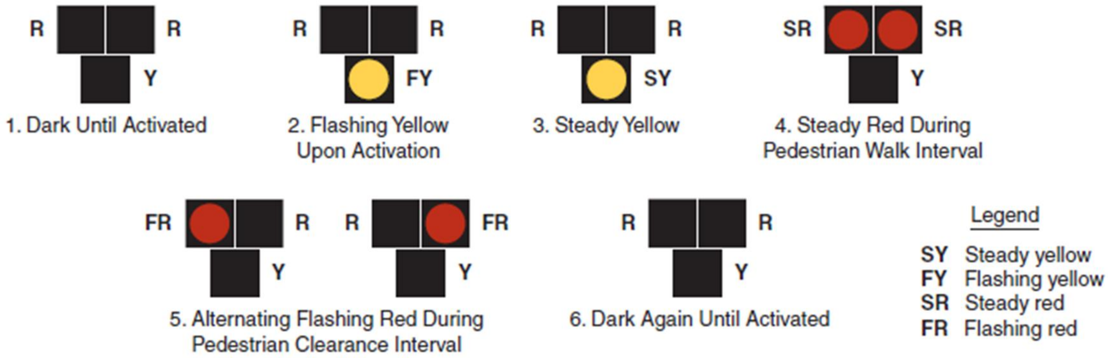
Base Image: City of Toronto

Figure 8 – Level 3: Enhanced Amber Beacon in Toronto, Ontario (digitally altered to show US MUTCD style signage)

Level 4: Pedestrian hybrid beacon (PHB). This type of crossing is functionally similar to a mid-block traffic signal, but uses a three-head display facing motorized traffic, along with signal heads that tell pedestrians when to cross (**Figure 9**). A PHB consists of two horizontally arranged red lenses above a single yellow lens in an overhead-mounted signal display. The signal face remains unlit until activated by a pedestrian. Until activated, the pedestrian display shows a “Don’t Walk” indication. The system is activated by a pedestrian by pushing a button located on a pole or post at the roadside. The beacons flash yellow, followed by a steady yellow interval, and then by a steady red signal. This sequence alerts vehicles to slow, and eventually stop while pedestrians have the right-of-way to cross the street, in exchange for a minor increase in pedestrian delay. While motorists see steady red beacons, the “Walk” sign is lit for pedestrians. After the “Walk” phase ends, the pedestrian signal changes to a flashing “Don’t Walk” sign and the PHB flashes alternating red lights to the motorists. The display sequence for motorized traffic is illustrated in **Figure 10**. There is no green display aspect; instead the signal goes dark after each cycle. PHBs may be put into coordination with adjacent traffic signals by tying into an existing controller, if close enough to the signalized intersection, or requiring a separate controller. The crossing also includes signs and pavement markings.

Photo: formulaone/Flickr

Figure 9 – Level 4: Pedestrian Signal in Delaware



Source: MUTCD 11th Edition, Chapter 4J-3, FHWA

Figure 10 – PHB Display Sequence

Level 5: Mid-Block pedestrian signal. This type of crossing uses a full three-color (red/yellow/green) traffic signal display in addition to pavement markings and signs (and). Variations to this type of crossing include:

- Replacing the circular green aspect with a steady green arrow pointing upward (done in Los Angeles).
- Puffin crossing, which includes a system for detecting pedestrians that have not completed their crossing (**Section 4.4**). This variation has been implemented in the United Kingdom (UK) and British-influenced countries.

- Pelican crossing, (**Section 4.4**), an older design used in the UK and British-influenced countries.

These treatments give pedestrians the immediate priority once activated, being served similar to a side street at a semi-actuated signal. Depending on site conditions and agency policies, mid-block signals can be configured either to give immediate priority to pedestrians, or to hold pedestrians temporarily to maintain vehicular progression along a corridor. Pedestrian signals may be put into coordination with adjacent traffic signals by tying into an existing controller, if close enough to the signalized intersection, or requiring a separate controller. See **Section 9** and National Cooperative Highway Research Program (NCHRP) Report 812 for additional information regarding isolated and coordinated pedestrian signals.

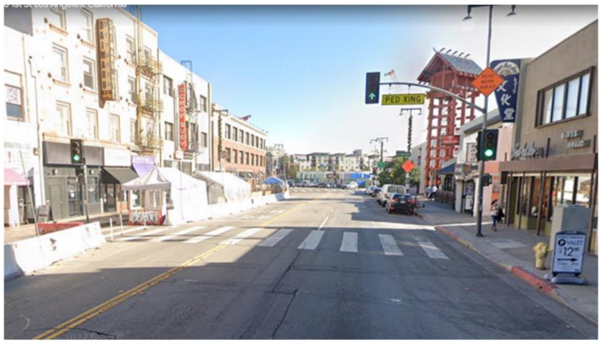


Image: Google Earth

Figure 11 – Level 5A: Mid-block Pedestrian Signal (MBPS), Los Angeles, CA

Image: John Shaw/Iowa State University

Figure 12 – Level 5B: Mid-block Pedestrian Signal, Ames, IA

Level 6: Grade separation. This type of crossing physically separates pedestrians from motorized traffic by means of an underpass or overpass (**Figure 13** and **Figure 14**).

Photo: Besopha/Flickr

Figure 13 – Level 6: Pedestrian Overpasses Can be Opportunities for Expressions of Architectural Creativity and Civic Pride

Photo: InSapphoWeTrust/Wikimedia Commons CC 2.0

Figure 14 – Level 6: Colorful Artificial Windows Make the 850-foot Pedestrian Tunnel Connecting O'Hare International Airport Concourses B and C more Inviting

1.3. Pedestrian Treatment Enhancements

1.3.1. Raised Crosswalks

The safety of pedestrian crossings on lower-speed (35 mph or less) facilities can be enhanced by providing a raised crosswalk (**Figure 15**). This relatively low-cost treatment functions as a speed table (a speed hump with wide, flat top), reducing the likelihood of a vehicle-pedestrian crash and the injury severity if one occurs.

1.3.2. Two-Stage Crossings

Previous research has identified many advantages (and very few disadvantages) for using two-stage pedestrian crossings with an offset, fenced median refuge (**Figure 16**). In general, previous research has found the following regarding two-stage crossings:

- Increase pedestrian safety.
- Reduce pedestrian delays when crossing busy roadways.
- Reduce motorist delays, since motorists only have to wait for pedestrians to cross half of the roadway.
- Make it possible to optimize the traffic signal timing plan for two-way progression regardless of the spacing between the mid-block crossing and the adjoining signalized intersections.

Conclusions regarding pedestrian delay found through this research report can be found in Section 9.3.2.

The British Department for Transport (DfT) has sponsored extensive research on pedestrian crossing safety features. DfT's fenced median refuge design has been optimized for the safety and convenience of all road users, and this design has been adapted for use in Arizona (**Figure 16**) and a handful of Nevada locations. It includes the following features:

- The entry and exit locations of the refuge are offset, and the refuge is fenced, to prevent pedestrians from crossing in a single stage.
- The direction of the offset and the locations of the pedestrian pushbuttons are arranged to direct pedestrian attention toward oncoming traffic.

Photo: Scott Batson/Wikimedia Commons

Figure 15 – An Unsignalized Raised Crosswalk in Portland, Oregon

Photo: Arizona DOT

Figure 16 – Fenced Median Refuge in Arizona, Based on British Design

1.3.3. Other Safety Features

Based on safety research, DfT has standardized the use of radar-based on-crossing pedestrian detectors. If a pedestrian has not finished crossing before the end of the pedestrian clearance interval, these detectors trigger an extension of the pedestrian clearance interval. Thus, they provide additional safety for slowly-moving or unpredictable pedestrians such as children, people with severe disabilities, and impaired pedestrians. This feature would be relatively simple to add to the modern signal controllers typically used in Nevada.

A further refinement sometimes used in British installations is a radar-based detector aimed at the sidewalk approaching the crossing, which cancels the pedestrian call if the pedestrian disappears. In most cases this means the pedestrian has either crossed against the light, or departed after deciding not to cross. In the UK this feature appears to be used selectively based on past history of false activations. This reduction in spurious activations is said to increase drivers' respect for the signal and thereby improve driver compliance.

1.4. Pedestrian Treatment Selection Overview

Table 1 summarizes the typical application environments for the mid-block pedestrian treatments considered in the present study. These include rectangular rapid-flashing beacons (RRFBs), enhanced amber beacons (EABs), pedestrian hybrid beacons (PHBs), and three-color mid-block traffic signals, along with grade separations. Most of these treatments can be combined with one or more of the enhancements shown in **Table 2**. Specifically, in low-speed environments pedestrian safety can be enhanced through the use of a raised crosswalk that functions as a speed table. Similarly, wherever the available road space is sufficiently wide, any of the treatments can be enhanced with a median refuge to provide a two-stage crossing, which will benefit both pedestrian safety and the efficient flow of motorized traffic.

Table 1 – Typical Application Environments for Mid-Block Pedestrian Treatments

Level	Treatment	Typical Application Environments	Typical Speed Limit
1	Marked pedestrian crossing	Sites with low pedestrian volume	Up to 55 mph
2	Rectangular Rapid-Flashing Beacon (RRFB)	Roadways with low to moderate pedestrian volume on relatively narrow low-speed residential collector streets or low-speed streets in traditional storefront commercial areas	Up to 35 mph
3	Enhanced Amber Beacon (EAB)	Roadways with low to moderate pedestrian volume on relatively narrow urban collectors or minor arterials	Up to 40 mph
4	Pedestrian Hybrid Beacon (PHB)	Wide (multi-lane) roadways, high-speed arterials, locations with high pedestrian volume, locations with limited sight distance, sites with intermittent bursts of heavy pedestrian activity such as entertainment venues and stadiums	Up to 55 mph
5	Mid-block Pedestrian Signal (MBS)	Sites meeting MUTCD mid-block signal warrants, typically on busy arterials	Up to 55 mph
6	Grade Separation	Freeway crossings, sites with very high pedestrian volumes	N/A

Table 2 – Typical Application Environments for Mid-Block Pedestrian Treatment Enhancements

Code	Treatment	Typical Application Environments	Typical Speed Limit
X	Raised Crosswalk	Residential streets, collectors, minor arterials in storefront commercial areas	Up to 35 mph
M	Median Refuge	Multi-lane collectors and arterials	Up to 55 mph

Grade separation using an overpass or underpass is mandatory when pedestrians must cross a freeway or other very high speed, very high volume facility. A common example in the Western US is passenger access to transit stations located in the freeway median. In spite of their considerable capital costs, grade separations can also be desirable in locations with high pedestrian volumes--not only to prevent pedestrian crashes but also to reduce motorist delays. The set of four pedestrian overpasses at S Las Vegas Blvd and E Flamingo Road in Las Vegas is an example of a location where grade-separated crossings benefit all road users. In some cases, grade separations can be fully integrated with the architecture of adjacent buildings to provide seamless connections at the second- or third-floor level.

Many pedestrian crossings in the United States are currently undertreated, while some are overtreated. This can potentially be attributed to the lack of a treatment hierarchy in national guidance documents. In addition, the literature review conducted for this project revealed great inconsistency in the methods agencies have used to select pedestrian crossing treatments in the past. Some agencies have relied on very rigid numerical criteria (typically combinations of pedestrian and vehicular volume) while others recommended considering a wide range of hard-to-quantify factors such as land use, pedestrian age and ability, and even the economic development goals for the area near the crossing.

In a balanced approach, objective criteria can be used to identify minimum treatment thresholds. With these minimums in mind, a higher level of treatment (or treatment enhancements such as a raised crosswalk or median refuge) can be applied at sites with complications such as limited visibility, extreme peaking of pedestrian demand, or frequent use by elderly or intoxicated pedestrians.

Toward this end, the project team developed a recommended treatment hierarchy (Figure 2) and a Microsoft Excel based Nevada Pedestrian Treatment Evaluation Workbook that takes four readily measurable factors into consideration (posted speed limit, roadway configuration, motorized traffic volume, and pedestrian traffic volume). Using this information, the worksheet generates star ratings for six potential treatments. In addition, the workbook performs an economic analysis based on the pedestrian safety benefits of the treatment.

A few hard-and-fast rules are built into the workbook. For example, the workbook returns a zero-star rating for RRFB applications on high speed (40+ mph) roadways, indicating this not a recommended application of the RRFB. Similarly, only a grade separation is considered acceptable when crossing a freeway. The first rule reflects the results of studies identified through the literature review, which indicate that motorist compliance with RRFBs deteriorates markedly in high-speed environments. Simply stated, when the traffic is moving quickly, it needs to be brought to a stop before pedestrians are allowed to cross. From this perspective, "red" devices that mandate a stop (PHBs and mid-block signals) can be clearly separated from "yellow" devices that simply warn of possible pedestrian presence (RRFBs and EABs).

A number of field conditions potentially justify the use of a higher-level treatment. For example, the use of a "red" device is strongly recommended for sites where motorists cannot readily see the approaching pedestrians, such as may be the case when a pedestrian path or bike trail crosses a roadway on a skew (a situation that occurs frequently when abandoned railroad corridors are converted to multi-use trails). Other examples of conditions which could necessitate the use of a higher treatment level include, but are not limited to, extreme peaking of pedestrian demand and frequent use by highly vulnerable pedestrians such as children, elderly people, people with disabilities, and intoxicated people (i.e., proximity to establishments that serve alcohol or other intoxicants).

1.5. Pedestrian Crossings Near Intersections

The traffic signal spacing in major Nevada cities is long compared to most other parts of the United States. For example, one-mile signal spacing is not unusual on Las Vegas area arterials that adjoin populous small-lot single-family residential districts. The relatively long distances between signals increase the likelihood that pedestrians will cross mid-block instead of backtracking to a signalized intersection. There are potentially locations where adding intermediate signal(s) that serve both pedestrians and side-street traffic would be preferable to adding mid-block pedestrian crossings. One potential rule of thumb is to compare the signal spacing with the spacing of bus stops, bearing in mind that at most bus stops, approximately half of passengers must cross the roadway to reach their ultimate destination.

RRFBs, EABs, PHBs, and mid-block signals were all designed for true mid-block crossings--those which do not coincide with a street or major commercial driveway. The Manual on Uniform Traffic Control Devices (FHWA 2009) cautions against the use of PHBs near intersections, stating that a PHB "*should* be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs" (emphasis added). No comparable language is provided for RRFBs in FHWA Interim Approval 21 (FHWA 2018).

When a pedestrian crossing is located at or near a three-leg intersection, the first order of business is to determine whether the site requires a mid-block pedestrian treatment, or is better suited to a regular three-color traffic signal that serves both pedestrians and side-street motorized traffic. At such sites, the MUTCD traffic signal warrants should be reviewed. This is particularly important if a PHB is under consideration, given that the cost of installing and maintaining a PHB differs only marginally from the cost of a traffic signal.

Perhaps because of the MUTCD's admonishment against of the use of PHBs near intersections, the existing research literature contains very little discussion of the use of mid-block pedestrian treatments at or near four-leg intersections. An important question is whether the side-street traffic will be able to readily determine when the device is illuminated. If vehicles on the side street are unaware that a device such as a PHB is illuminated and pedestrians have the right-of-way, there could be an increased risk of a pedestrian being struck by a vehicle turning from the side street.

1.6. Simulation Modeling Results

This research compares pedestrian treatments including options that immediately service pedestrian demands (RRFBs and EABs) with pedestrian signals that function similar to “regular” traffic control signals. To gain a better understanding of how mid-block pedestrian treatment selection affects vehicular and pedestrian delays, the project team used PTV Vissim 2023 software to model a total of 180 combinations of roadway geometrics, pedestrian volume, vehicular volume, mid-block crossing design (single vs two-stage), mid-block crossing type, and signal operation strategy (isolated vs coordinated). As discussed in more detail in Chapter 9, some technical limitations of the software were addressed in consultation with NDOT and the technical advisory committee. These included modeling RRFBs using the Vissim "priority rules" feature, and modeling PHBs as mid-block signals with timing plans designed to mimic PHB operations. Although the model runs do not cover all possible combinations that occur in Nevada, some conclusions can be drawn based on the analysis. For clarity, these are described below from the separate perspectives of vehicular and pedestrian road users.

1.6.1. Vehicular Perspective

- In the models, vehicular delays at RRFBs became excessive when the pedestrian volume exceeded approximately 75 to 100 ped/h. The threshold depends on the conflicting vehicular traffic volume and the width of the pedestrian crossing. The breakdown threshold is higher if a two-stage crossing is used at the RRFB. The results depend on the assumption that the pedestrian warning would be given immediately upon pedestrian activation with the RRFB, and that drivers would comply with this warning. In the simulation model, as the pedestrian volume grew to a moderate level, vehicular traffic flow was extremely restricted.
- Two-stage pedestrian crossings generally reduced the vehicular delays compared to single-stage crossings, and this is likely to be the case for all four types of signalized mid-block crossings (RRFBs, enhanced amber beacons, PHBs, and mid-block signals). These benefits are greatest under high vehicular and pedestrian volumes. The models assumed a 30-second minimum green time for the vehicular traffic in the case of isolated pedestrian signals, and an effective minimum green time equal to half the corridor cycle length minus the pedestrian interval durations in the case of coordinated pedestrian signals.
- The benefit to drivers derives from two sources. First, a two-stage crossing will almost always reduce the stopping time for motor vehicles, since they only have to wait for the pedestrians to cross half the roadway. Second, in corridors with coordinated signals the use of two-stage crossings makes it easier to obtain efficient two-way traffic progression,

especially if a mid-block crossing is asymmetrically spaced between the upstream and downstream signals.

- Under the optimized traffic signal timings developed for this project, the benefits of coordinating of the PHB with the corridor signal timing plan were relatively small for the modeled scenarios. The benefits of coordination appear to be somewhat greater when the timing plan is sub-optimal, but this line of investigation was not pursued in depth in the present study.
- Per unit of expenditure, implementing isolated PHBs (or isolated MBSs) is likely to yield greater overall benefit to road users than implementing coordinated PHBs (or coordinated MBSs). If a single PHB is being added to an existing coordinated corridor, the cost-effectiveness of coordinating the PHB will vary with the interconnection technology and communications infrastructure available at the site. Conversely, if coordination is being added along an entire corridor, it will generally be advantageous to include mid-block pedestrian crossings as part of the coordinated system.

1.6.2. Pedestrian Perspective

- RRFBs yielded lower pedestrian delay than pedestrian signals. Results assumed immediate provision of the flashing indication on pedestrian actuation, and that vehicles always immediately yield to a pedestrian when one is present.
- In terms of delay, single-stage isolated PHBs are the second-best option for pedestrians. They are preferable to RRFBs in terms of driver compliance and pedestrian safety.
- Under the optimized signal timings, isolated two-stage PHBs result in a modest increase in pedestrian delay for pedestrian volumes less than about 100 ped/h. These delays increase sharply at volumes over 200 ped/h.
- In general, coordinated two-stage PHBs result in substantial pedestrian delays (typically two waiting periods of 45-60 seconds each).

1.7. Study Limitations

Key limitations of the present study are as follows:

- The Vissim software is not designed to model illegal road user behavior. RRFBs were modeled using the Vissim "priority rules" feature, which had the effect of assuming 100% compliance with laws requiring drivers to yield to pedestrians. Average pedestrian delays will be somewhat longer, and average motorist delays marginally shorter, if motorists fail to comply with these laws.
- Although the software could not explicitly model the flashing red phase for PHBs, these devices were modeled as mid-block signals and the timing plans were designed to mimic the operation of a PHB as closely as possible. Details are discussed in Chapter 9.
- Due to a lack of empirical field data, it was not possible to validate the Vissim modeling results for the capacity limitations of RRFB devices. Specifically, under high pedestrian volumes the driver behavior at RRFBs is largely unknown.
- Although modeling was completed for 180 combinations mid-block crossing device type and site conditions, many more combinations potentially occur within the state of Nevada. In particular the present results may not be fully applicable to core urban areas with short block lengths and intense pedestrian traffic.

1.8. Recommendations for Future Research

Several recommendations for future pedestrian crossing safety research are presented at the end of **Section 10**.

2. INTRODUCTION

From 2015-2019, Nevada averaged 73.6 pedestrian fatalities per year, a per capita pedestrian death rate 36% above the national average. In addition, according to medical data compiled by the US Centers for Disease Control & Prevention (CDC), each year about 625 Nevada pedestrians required hospitalization after being struck by a motor vehicle, and more than 1500 were treated and released at emergency departments. When all costs are considered, these crashes resulted in losses incurred by insurers, taxpayer-funded healthcare programs, employers, pedestrians, and families totaling well over $1 billion per year. More than a third of vehicle-pedestrian crashes occurred when pedestrians were crossing urban, suburban, or small-town streets at mid-block locations.

Many urban and suburban roadways in Nevada are wide and straight, with long distances between intersections and high travel speeds. Safely crossing these roadways can be difficult for pedestrians, with notable risks for children, elderly people, and people with disabilities. In fact, pedestrians account for nearly 25% of all Nevada fatalities and 15% of serious injuries, with about 90% of these fatalities occurring in Clark and Washoe Counties. Although these fatalities and serious injuries take place in a variety of settings, one notable point of vulnerability is crossings of urban and suburban arterials.

Numerous treatments have been devised to improve safety at pedestrian crossings, ranging from simple painted crosswalks to sophisticated signal systems and grade separations. Historically there has been a lack of clarity about which treatments are the most suitable for specific locations. To address this knowledge gap, this research project developed device selection criteria for corridors with mid-block pedestrian crossings The criteria are based on evidence gathered through literature review, stakeholder outreach, and traffic simulations. In addition, the project explored the effects of treatment type on pedestrian and motorist traffic delays. The overall goal is to maximize pedestrian safety while avoiding unnecessary delays to motorized traffic.

Rectangular rapid-flashing beacons (RRFBs) and pedestrian hybrid beacons (PHBs) are two of the most widely-used types of mid-block pedestrian signalization. An important element of this research was to identify criteria for the appropriate use of RRFBs and PHBs, along with their impacts on traffic flow and signal timing in busy corridors. Neither the legal status of PHBs in Nevada nor a detailed analysis of gap data at signalized crossings are included in this research.

2.1. Pedestrian Crossing Treatments

There are seven main categories of pedestrian crossings, which are illustrated and described in detail in **Section 1.3** and **Appendix A**. These treatments have differing physical characteristics, operational requirements, safety performance, installation costs, and maintenance requirements. Briefly, they are as follows:

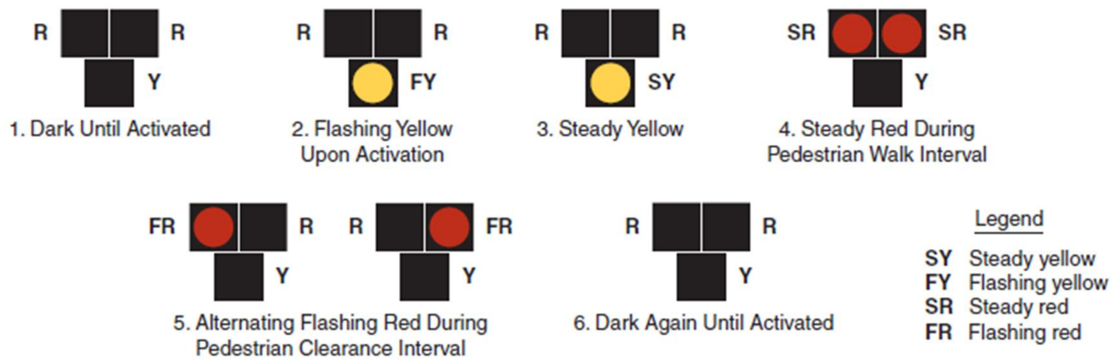
Level 0: No treatment. There is no delineated pedestrian crossing location. Pedestrians can potentially cross anywhere along the roadway frontage. As a result, pedestrian trajectory is often somewhat diagonal to the traffic lanes.

Level 1: Unsignalized marked pedestrian crossing. This type of crossing is delineated by signs and pavement markings. Some sites have overhead illumination, but in US practice there are no warning beacons or signals. In the international literature this is referred to as a zebra crossing due to the pavement marking pattern frequently used in Europe. In the United Kingdom (UK) and several British-influenced countries, the zebra crossing is often augmented with a large continuously illuminated amber globe called a Belisha beacon.

Level 2: Rectangular rapid-flashing beacon (RRFB). This type of crossing has signs, pavement markings, and pairs of post-mounted (or sometimes overhead-mounted) amber beacons that flash an in a wig-wag pattern for several seconds after activation by a pedestrian. **Section 9.4** provides advice about setting this interval.

Level 3: Enhanced pedestrian-activated amber beacon (EAB). This type of crossing is similar to an RRFB but includes both post-mounted and overhead-mounted full-size circular amber beacons, which flash for several seconds after activation by a pedestrian for enhanced visibility. **Section 9.4** provides advice about setting this interval. The crossing also includes signs and pavement markings.

Level 4: Pedestrian hybrid beacon (PHB). This type of crossing is functionally similar to a mid-block traffic signal, but uses a three-head display facing motorized traffic, along with signal heads that tell pedestrians when to cross. The display sequence for motorized traffic is illustrated in **Figure 17**. There is no green display aspect and the signal goes dark after each cycle. The crossing also includes signs and pavement markings.



Source: MUTCD 11th Edition, Chapter 4J-3, FHWA

Figure 17 – PHB Display Sequence

Level 5: Mid-Block pedestrian signal. This type of crossing uses a full three-color (red/yellow/green) traffic signal display in addition to pavement markings and signs. In Los Angeles, the circular green aspect is replaced by a steady green arrow pointing upward. In the UK and British-influenced countries this is called a Pelican or Puffin crossing; the latter includes a system for detecting pedestrians that have not completed their crossing.

Level 6: Grade separation. This type of crossing physically separates pedestrians from motorized traffic by means of an underpass or overpass.

2.2. Background and Purpose

The current practice for treatment of unsignalized crossings follows the Traffic Operations Process Memorandum 2022 Traffic Operations and Safety Study Procedures. While PHBs are included as a treatment option in the decision matrix, the Nevada Department of Transportation (NDOT) typically installs RRFBs as opposed to PHBs. In other states, RRFBs are primarily used on low-speed and medium-speed facilities with relatively low traffic volumes, while PHBs or mid-block pedestrian signals are the main treatment for arterials. This research aims to provide practitioners with the best-available information about the most suitable pedestrian crossing treatments for various traffic environments to improve pedestrian safety and vehicle operations.

2.3. Document Organization

This document is organized into the following sections:

- **Section 1** is an executive summary of the research report and project
- **Section 2** details pedestrian crossing treatments, the project background, and purpose of the research.
- **Section 3** summarizes the Technical Advisory Committee (TAC) meetings held during this research.
- **Section 4** contains a summary of a literature review conducted for potential pedestrian signal implementation.
- **Section 5** summarizes a state of the practice review of pedestrian signal implementation across the nation.
- **Section 6** contains information regarding pedestrian crashes in Nevada.
- **Section 7** contains information regarding pedestrian crashes in Nevada.
- **Section 8** presents the Preliminary Treatment Selection Guide for Pedestrian Crosswalk Treatments developed as part of this research.
- **Section 9** summarizes microsimulation modeling and timing recommendations for two test locations completed as part of this research.
- **Section 10** provides recommendations resulting from the research for implementation of pedestrian signals in Nevada.
- **Section 11** provides references to sources used in the research.
- **Appendices** are included to provide supporting project documentation.

3. TECHNICAL ADVISORY COMMITTEE

The project team would like to express their gratitude to the members of the project's Technical Advisory Committee (TAC) which was comprised of representatives from the following organizations:

- NDOT Districts 1, 2, and 3
- NDOT Engineering, Operations, and Planning Divisions
- RTC Washoe (Reno, Sparks, Washoe County)
- RTC SNV (Las Vegas, Henderson, North Las Vegas, Clark County)
- Carson Area Metropolitan Planning Organization (CAMPO)
- Tahoe Regional Planning Authority (TRPA)
- Nevada Highway Patrol (NHP)
- Law Enforcement
- UNLV School of Medicine
- Regional Emergency Medical Services Authority (REMSA)

The text that follows summarizes the TAC activities completed throughout the project.

3.1. TAC Meeting #1

TAC Meeting #1 was held on Wednesday, November 10th, 2021. The meeting included an update on the literature review, interviews (state of the practice review), a crash data overview, and discussion on potential locations for signal timing research.

The literature review and project focus is on pedestrian treatment selection and operations. Safety benefits utilized in the study are based on previous research which resulted in RRFBs and PHBs being identified as FHWA Proven Safety Countermeasures. Also clarified was the focus of this research is not on whether PHBs are legal in the state of Nevada. Included in this is the legislation that prohibits vehicles from passing through a dark signal without stopping.

A summary of the interviews is provided in **Section 5** of this document. Interviews were conducted with in state and out-of-state representatives including locations in Texas, Michigan, Virginia, North Carolina, Tennessee, Colorado, and others.

Potential locations for signal timing research in the state of Nevada were discussed and attendees noted there may be some benefit to studying locations with existing RRFB deployment rather than just looking at locations with no treatments currently deployed. Also, attendees noted that it could be beneficial to study more locations with varying conditions considering signal density, number of lanes, varying volumes, etc.

3.2. TAC Meeting #2 and #3

TAC Meeting #2 and #3 was combined and held on Thursday, May 12th, 2022. The meeting included a literature review update, crash data memo review, and state of the practice and interviews review.

A summary of the literature review completed for the study was presented. Topics covered included the following: two-stage vs. one-stage crossings, proximity to pedestrian generators, land uses, as well as other contextual variables. The literature review identified a clear tension between prioritizing pedestrian and vehicle interests and considerable variability regarding selection thresholds for pedestrian crossing treatments. A general hierarchy regarding treatments for pedestrian crossings was identified, with PHBs falling between mid-block signals and amber beacons or RRFBs.

Information from a crash data review for the state of Nevada identified that fatal and serious injury pedestrian crashes are high in Nevada, with approximately 70% of the pedestrian crashes in Nevada occurring on arterial roadways. Many of these same crashes occur along roadways with speed limits between 30 and 49 MPH. **Section 5** of this document contains additional information on pedestrian crashes in Nevada.

Information regarding the two data collection locations selected for this research were presented. The first location, Bonanza Road and 23rd Street, was selected because it was a recommendation from the NDOT Bonanza Road Safety Management Plan (December 2021). It also serves as an example of a location where the pedestrian crossing is not located halfway between two traffic signals.

The second location, Martin Luther King Boulevard and Balzar Avenue, was chosen because there is an existing RRFB at this location. This location serves as an example of a location of a crossing located halfway between two traffic signals. Additionally, it is believed that pedestrian volumes are high in this location due to the proximity of Booker Elementary School.

Additional location information is provided in **Section 9** of this document.

3.3. TAC Meeting #4

TAC Meeting #4 was held on Tuesday, December 13th, 2022. The meeting introduced the Pedestrian Treatment Evaluation Workbook, application guide, and preliminary results for the two locations identified previously.

There was discussion regarding two-stage PHB crossings, whether the workbook accounts for medians, and how speed is involved in the treatment selection. Examples of two-stage PHB crossings across the country were reviewed.

Additional information regarding the Treatment Selection Workbook and application results are provided in **Section 7** and **Section 8** of this document.

3.4. TAC Meeting #5

TAC Meeting #5 was held on Tuesday, April 11th, 2023. The meeting reviewed initial microsimulation results and final recommendations.

The project team reviewed the various Vissim modeling results and associated delays with each analyzed scenario for each corridor. The team also presented videos showcasing one-stage and two-stage pedestrian treatments on the Martin Luther King Boulevard corridor.

There was discussion if conclusions could be made regarding the pedestrian volumes below 200 per hour. It was noted that while RRFBs perform well under this threshold of pedestrian volumes, the decision to implement an RRFB versus a PHB is still determined by other factors as well (i.e., speed, crossing distance, volume, etc.). These other factors have already been defined in the Pedestrian Treatment Hierarchy and the tool developed for the project.

Additional information regarding the microsimulation modeling and recommendations are provided in **Section 9** and **Section 10** of this document.

4. LITERATURE REVIEW SUMMARY

This section summarizes the results of a comprehensive literature review conducted for the project. The full literature review including citations, methodology, and a complete overview of the identified studies and existing national guidance on mid-block pedestrian treatments is provided in **Appendix B**.

4.1. Methodology

The project team completed a comprehensive review of the pedestrian safety treatment selection and site selection literature. Systematic searches were completed using four scholarly databases (Ebsco Host Academic Search Ultimate, SafetyLit, Transportation Research International Documentation [TRID], and the TRL Library). The searches yielded a total of 150 unique publications from academic journals and conference proceedings.

The 150 publications were screened for relevance on the basis of their titles and abstracts, and publications that survived the first screening were subject to full-text review in the second screening. This yielded 29 publications relevant to site selection and treatment selection for mid-block pedestrian crossings, which are summarized in **Appendix B**. These were augmented with non-academic sources such as national guidelines, and with additional documents found through supplemental searches. Together, the publications serve as a record of the struggle to define pedestrian crossing treatment selection criteria over the past half-century.

4.2. Lack of Consensus on Pedestrian Treatment Criteria

Over the years, agencies and researchers have developed selection guidance that ranges from rigid criteria based solely on pedestrian and vehicular volumes, to loose frameworks that ask the analyst to consider a wide range of subjective factors. There is ongoing tension between using criteria that are simple and easy to measure (such as pedestrian counts, vehicle counts, and traffic speeds) and more subjective criteria (such as the adjacent land use, the age and ability level of the pedestrians typically present at the site, and non-traffic policy goals such as promoting walkability to support the vitality of local businesses).

The research suggests a partial mismatch between the selection criteria used by agencies and the factors that concern pedestrians. Specifically, pedestrians tend to think about road crossings in terms of safety, route continuity (ease and directness of access to destinations), and comfort (minimization of delays, ease of use, avoidance of climbing grades/stairs, and so forth). In general, pedestrians tend to prefer signalized at-grade crossings, and are less enthusiastic about unsignalized crossings, overpasses, and underpasses. Pedestrians do not like situations where they are required to double-back to reach their destination. Indirection and grade changes are particularly troublesome for pedestrians with disabilities.

4.3. Site Selection (Planning) and Treatment Selection (Design)

Taken as a whole, the literature suggests a need for a two-phase site selection and treatment selection approach, specifically a planning phase and a design phase. The planning phase involves determining whether the location and spacing of existing pedestrian crossings is adequate, or whether there are unmet pedestrian needs. Some inadequacies are physically observable in the form of a beaten path, or can be identified from crash records indicating a concentration of pedestrian crashes in a specific area. In other cases, the locations where pedestrians cross the roadway are diffused along a broad expanse of roadway frontage, but can be channeled into a finite number of crossings. It is also necessary to consider whether pedestrian demand has been suppressed by the difficulty of crossing the roadway.

Planning tools mentioned in the literature include geographic information system (GIS) mapping of pedestrian generators (bus stops, schools, shopping areas, major employers, etc.) and prioritization techniques such as the Analytical Hierarchy Process (AHP) and the VIKOR multicriteria selection algorithm. In setting weighting factors for AHP or VIKOR, is necessary to balance the competing priorities of different stakeholder groups. For example, the needs of pedestrians with disabilities differ from those of ambulatory people.

The design phase involves determining the specific location of the crossing, which treatment to apply, and the details of the treatment. Examples include not only the type of crossing treatment, but also whether median refuges will be provided, and whether the pedestrian signal or beacon requires coordination with a corridor signal system.

4.4. Design Considerations

For single-stage mid-block crossings, the distance from the crossing to the adjacent signalized intersections is crucial for two-way signal progression. The optimal location is not always the midpoint between the two signals, and deviations from the optimal location heavily impact vehicular and pedestrian delay.

The literature identifies many advantages (and very few disadvantages) for using two-stage pedestrian crossings with an offset, fenced median refuge (**Figure 18**). In general, two-stage crossings are found to:

- Increase pedestrian safety.
- Reduce pedestrian delays when crossing busy roadways.
- Reduce motorist delays by making it easier to achieve two-way vehicular traffic progression along signalized corridors.
- Make it possible to optimize the traffic signal timing plan for two-way progression regardless of the spacing between the mid-block crossing and the adjoining signalized intersections.

Photo: Arizona DOT

Figure 18 – Arizona Pedestrian Crossing with Fenced, Offset Median Refuge

The British median refuge design has been optimized for the safety and convenience of all road users. It includes the following features:

- The entry and exit locations of the refuge are offset, and the refuge is fenced, to prevent pedestrians from crossing in a single stage (**Figure 18**).
- The direction of the offset and the locations of the pedestrian pushbuttons are arranged to force pedestrians to look toward the oncoming traffic (**Figure 18**).
- In newer designs known as Puffin crossings, the pedestrian signals have been moved to the near side of the crossing, reduced in size, and mounted in the same small box as the pushbutton. Far-side pedestrian signals are eliminated. The DON'T WALK indication appears when the button is pressed, providing visual acknowledgement of the pedestrian signal call (traffic approaching from the right on the one-way street shown in **Figure 19**). The placement of the box forces pedestrians to continue looking toward approaching traffic while waiting for the WALK indication, and makes the pedestrian signals invisible to motor vehicles to avoid draw-throughs and anticipatory starts. Sites incorporating these features have been shown to be substantially safer than the older Pelican crossing design, which is similar to North American practice. A typical Puffin crossing signal timing sequence is shown in **Figure 20**.

Note the two radar units mounted on top of the signal head which detect (a) the presence of pedestrians who have not finished crossing (unit angled toward the street) and (b) pedestrians waiting to cross (unit angled straight down).

Figure 19 – Typical Puffin Crossing and Near-side Pedestrian Signal Module with Pushbutton

	1	2	3	4	5	6	7	8	9
Vehicle Signal	Green	Amber	Red						Red Amber
Vehicle Instruction	Proceed if clear	Stop if safe	Wait at stop line						Wait at stop line
Pedestrian Signal	Red			Green	Red	Ext. Red	Red		
Pedestrian Instruction	Wait			Proceed if clear	Do not start to cross	Do not start to cross	Do not start to cross		

Figure 20 – Puffin Signal Timing Sequence

The most crucial design decision is whether the pedestrian assistance device will be red or amber, which is to say, whether a PHB or mid-block signal will be installed to make it mandatory for drivers to stop at the crossing, or whether motorists will simply be advised to yield to pedestrians by deploying some form of amber warning beacon. The literature points toward the need for traffic on high-speed roadways to be brought to a complete stop, with flashing beacons reserved for low-speed facilities where consequences of a fail-to-yield collision are less severe. Flashing amber devices are unlikely to be satisfactory if the AADT exceeds about 10,000 or the traffic speed exceeds 35 to 40 mph. Grade separation should be considered for sites with very high traffic speed, very high pedestrian traffic, or high motor vehicle traffic.

Several sources discuss numerical thresholds for pedestrian safety treatments, but there is divergence as to what the thresholds should be (**Figure 39** and **Figure 40** in **Appendix B**). In many cases the rationales for setting existing thresholds do not appear to be well documented. It appears that some of the thresholds were set to minimize traffic delays or limit the cost of installing and maintaining traffic control devices. This focus on vehicular traffic flow and agency costs contrasts sharply with the current US national policy of minimizing fatalities and serious injuries.

The Canadian guidance is particularly clear in setting out a hierarchy of pedestrian crossing treatments. As volumes grow and operational conditions become more complex, the treatment progresses from a marked crosswalk, to a crosswalk with RRFBs, to a crosswalk with RRFBs and overhead signs, to an enhanced crosswalk with overhead signs and large-diameter amber beacons (**Figure 21**), to a signalized mid-block crossing. This concept forms the basis of the treatment hierarchy recommended in **Section 7, Section 8,** and **Appendix A**.

Photo: City of Toronto). Photo altered to show US MUTCD style signage including overhead blank-out sign.

Figure 21 – Enhanced Amber Beacon System in Toronto, Ontario, Canada.

5. State of the Practice Review

This section summarizes key takeaways from interviews completed with various agencies in Nevada as well as throughout the country. Interviews outside of Nevada focused on agencies with existing PHB deployments. It is important to note that PHBs were not widely deployed throughout Nevada at the time the interviews were conducted. A compilation of full interview summaries is included in **Appendix C**.

Table 3 provides a summary of the interviews completed.

Table 3 – Summary of Interviews

Interview Group	Interviewee	Date of Interview
National	City of Austin, TX – Brian Craig	October 22, 2021
National	City of Boca Raton, FL – Maria Tejera	October 25, 2021
National	City of Memphis, TN – Nick Oyler	October 26, 2021
National	Oakland County, MI – Danielle Deneau	November 1, 2021
National	City of Raleigh, NC – Devin Smith	November 1, 2021
Nevada	RTC Washoe – Andrew Jayankura	October 19, 2021
Nevada	City of Henderson, NV – Eric Hawkins	October 20, 2021
Nevada	RTC Southern Nevada – John Penuelas	November 8, 2021
Nevada	City of Las Vegas, NV – Christina Karanikolas	December 8, 2021
Nevada	City of Sparks, NV – Amber Sosa	November 5, 2021
Nevada	City of Carson City, NV – Chris Martinovich	October 25, 2021
Nevada	Tahoe MPO – Melanie Sloan	October 25, 2021

Key Takeaways from interviews include the following:

- PHBs are preferred for pedestrian crossings on high-speed arterials.
- Suburban locations with big box commercial stores on either side of the street are good candidates for PHBs.
- Other potential locations for PHBs include trail crossings and bike crossings.
- PHBs are preferred when pedestrian volumes are high or intermittently high.
- PHBs can be preferable when placed in close proximity to schools to deal with intermittently high volumes of pedestrians.
- Many agencies prefer PHBs for locations near entertainment venues such as theaters or stadiums.
- PHBs are preferred in locations where motorists may not expect a pedestrian or bicyclist to cross the road, or where the pedestrian route is not readily visible from the street.

Desirable PHB characteristics for practitioners to consider:

- PHBs require traffic to stop, not yield, clearly designating right-of-way for the pedestrians.
- PHBs require all vehicular travel lanes to stop.

- PHBs have high conspicuity.

Undesirable PHB characteristics for practitioners to consider:

- Motorist familiarity can be low with PHBs.
- Pedestrians can be unfamiliar with how PHBs work.
- PHBs can often be expensive, depending on the location.
- PHB design and installation can be complex.

Interview takeaways regarding RRFBs:

- RRFBs are usually satisfactory for lower-speed, moderate vehicular volume applications, such as residential collector streets, traditional storefront-type commercial areas, pedestrian path crossings, bike trail crossings, etc.
- RRFBs are unsatisfactory on higher-speed arterials, areas with low motorist compliance, and locations with restricted sight distance. Motorist failure to yield to the pedestrian can be problematic when the pedestrian is approaching from the distant side of a single-stage crossing, especially at sites where pedestrian visibility is impacted by roadside features such as buildings, street furniture, landscaping, or parked vehicles.
- Visibility of pedestrians and RRFB signal heads can be poor on multilane roads, particularly at single-stage crossings.

6. Pedestrian Crashes in Nevada

This section provides information regarding pedestrian crashes in Nevada. Many urban and suburban roadways in Nevada are wide and straight, with long distances between intersections and high travel speeds. Safely crossing these roadways can be difficult for pedestrians, with notable risks for children, elderly people, and people with disabilities. In fact, pedestrians account for nearly 25% of all Nevada fatalities and 15% of serious injuries, with about 80% of these fatalities occurring in Clark and Washoe Counties. According to NDOT Crash data between 2015-2019, one notable point of vulnerability is crossings of urban and suburban arterials.

6.1. Lack of Pedestrian Volume Data Confounds Treatment Selection

A central quandary presented by the literature is that while treatments such as marked crosswalks, RRFBs, PHBs, mid-block signals, and pedestrian grade separations are implemented primarily as safety treatments, it is difficult to compute pedestrian exposure (and risk) due to the lack of comprehensive pedestrian traffic volume data. Thus, while the safety benefits of specific treatments can be estimated for reactive deployments at high-crash locations, it has been difficult to establish systemic deployment criteria for pedestrian treatments.

This situation contrasts markedly with the protection of railroad crossings, where automatic equipment can be used to count the daily numbers of trains and motor vehicles. As a result, it is easy to compute daily “exposure” by multiplying the two. For decades, exposure-based selection criteria have been used to define a four-step safety treatment hierarchy of “passive” crossings with only signage and markings, “active” crossings with warning lights, gated crossings, and grade separations. Evidence-based selection criteria have established for each treatment level and are broadly accepted by stakeholders. If it is possible to extend this computational logic to vehicle-pedestrian crossings, much of the treatment selection ambiguity could be resolved.

A comprehensive literature review is provided in **Appendix B**.

6.2. Crash Data

Crash data was provided by the NDOT for the years 2015-2019. The crash data included geolocation information and information regarding pedestrian involvement in a crash, as well as injury severity. For basic statewide fatal information, the Fatality Analysis Reporting System (FARS) was used. For the majority of analysis that includes crashes for all injury severities (not just fatalities), data from the Nevada Citation and Accident Tracking System (NCATS) was used.

6.2.1. Roadway Data

Various sets of roadway data were used for this crash data analysis. The datasets are discussed in the following sections.

6.2.1.1. Functional Classification

Data regarding the functional classification of roadways throughout Nevada was provided by NDOT. The Functional classification of a roadway is a US federal system for classifying roadways by their character of service. For example, Interstates are the first/highest functional classification and are documented as functional classification 1. These roadways are designed with long distance travel in mind and are considered limited access roadways where access to them is restricted to onramps, offramps, and interchanges with other interstates and freeways. Local roads, in contrast with freeways, are the lowest functional classification and are documented as functional classification 7. These roadways are often used for the origin or destination of a trip. Roadway functional classifications are listed in in **Table 4**.

Table 4 – Roadway Functional Classifications

Functional Classification	Roadway Type
1	Interstate
2	Other Freeways and Expressways
3	Other Principal Arterial
4	Minor Arterial
5	Major Collector
6	Minor Collector
7	Local

Source: Federal Highway Administration (FHWA)

6.2.1.2. Speed Limit

Speed limit data on roadways throughout Nevada was provided by NDOT. Data for speed limits throughout Nevada is incomplete, so the crash data used in conjunction with this dataset was used only where data was available.

6.2.1.3. Roadway Geometry

Information on intersections and curves along roadways in Nevada was provided by NDOT. Curve data is only available for roadways with a functional classification between 1-6 (not on local roads – functional classification 7). Information presented on roadway geometry is limited to functional classifications 1-6.

6.2.2. US Census Data

In order to analyze whether pedestrian crashes occurred in urban or rural areas, data from the US Census was obtained. The US Census publishes GIS data identifying urban and rural areas in the United States. According to the Census Bureau, these urban areas represent densely developed territory, and encompass residential, commercial, and other non-residential urban land uses.

6.3. Crash Data Overview

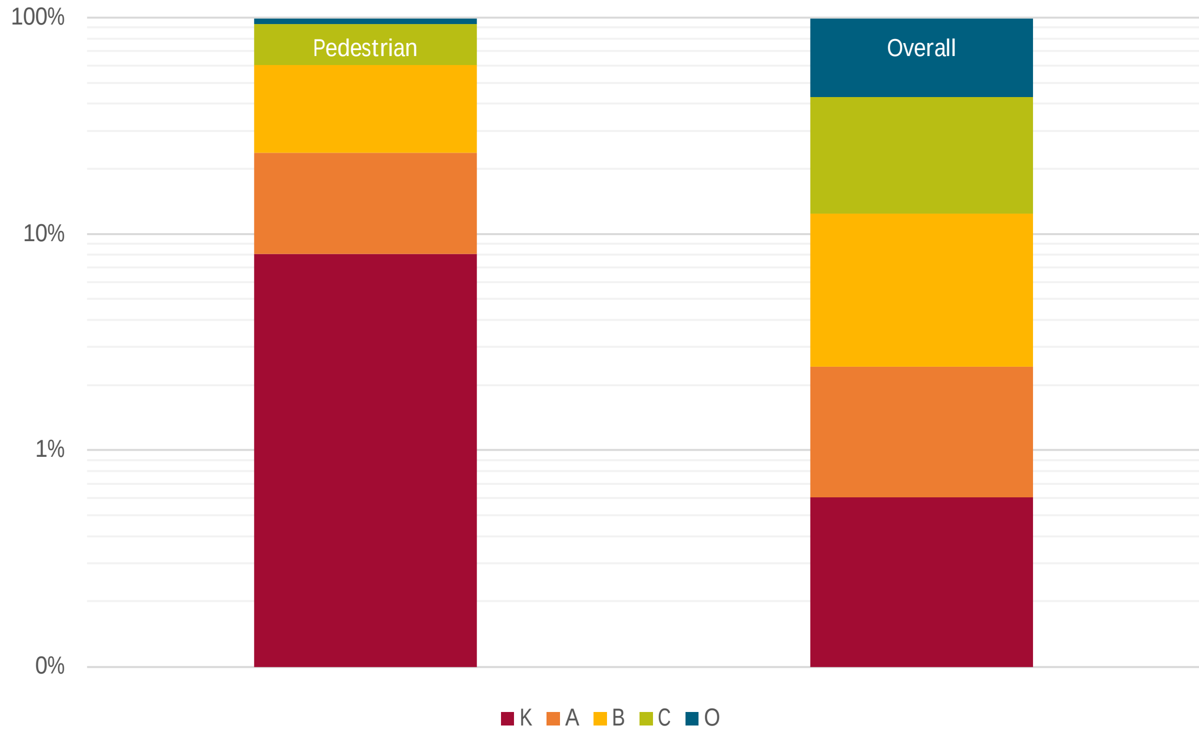
According to the FARS, pedestrians account for 23.6% of Nevada's total fatalities. Between 2015-2019, pedestrian fatalities in Nevada generally increased. During this same period the majority of these crashes occurred in urban areas, with over 73% occurring in Clark County. Forty-eight percent (48%) of fatal pedestrian crashes in Nevada occurred between Thursday and Saturday, and over fifty percent (50%) of all fatal pedestrian crashes in Nevada occurred between 6:00 PM and 12:00 AM. Over three-quarters (76%) occurred during nighttime. Since the FARS only includes fatal crash information, the NCATS was used to provide data on all pedestrian crashes.

The breakdown of pedestrian crashes in Nevada by injury severity is included in **Table 5**. In contrast with many other crash types, pedestrian crashes are often more severe. As shown in the table, roughly 8% of all pedestrian crashes result in a fatality, with another 15% resulting in a serious injury. In total, almost one-quarter of pedestrian crashes result in a fatal or serious injury. **Figure 22** demonstrates pedestrian and overall crashes by injury severity.

Table 5 – Pedestrian Crashes by Injury Severity

Speed Limit	Pedestrian		Overall	
	Crashes	%	Crashes	%
K	362	8.0%	1,479	0.6%
A	705	15.6%	4,473	1.8%
B	1,638	36.2%	24,278	10.0%
C	1,501	33.2%	74,252	30.4%
O	288	6.4%	139,402	57.2%
Total	4,494	100.0%	243,884	100.0%

Source: 2015-2019 Crash Data obtained from NDOT.



Source: 2015-2019 Crash Data obtained from NDOT.
Note: The Y-Axis of this figure is on a logarithmic scale.

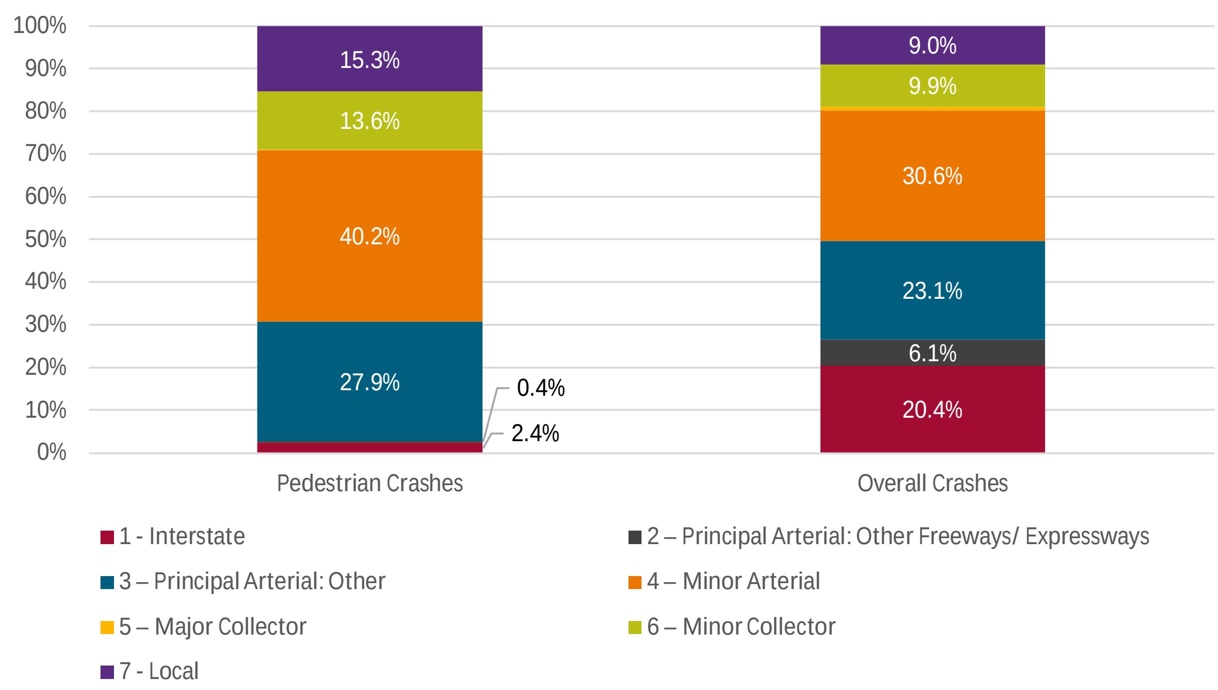
Figure 22 – Pedestrian Crashes and Overall Crashes by Injury Severity

Table 6 shows crashes involving pedestrians by the functional classification of the roadway. While Principal Arterial: Other and Minor Arterial roadways (Functional Class 3 and 4) make up less than 10% of the roadway mileage in Nevada, they account for 68% of pedestrian crashes. In contrast, while Local roadways (Functional Class 7) account for 74.4% of roadway mileage in Nevada, only 15.3% of pedestrian crashes occur along these roadways. **Figure 23** exhibits pedestrian and overall crashes by functional classification.

Table 6 – Pedestrian Crashes by Functional Classification

Functional Classification	Pedestrian		Total		Miles of Roadway	
	Crashes	%	Crashes	%	Miles	%
1 - Interstate	107	2.4%	49,818	20.4%	618.3	1.6%
2 – Principal Arterial: Other Freeways/ Expressways	18	0.4%	14,899	6.1%	55.2	0.1%
3 – Principal Arterial: Other	1,265	27.9%	56,276	23.1%	1,898.0	4.8%
4 – Minor Arterial	1,822	40.2%	74,636	30.6%	1,610.3	4.1%
5 – Major Collector	6	0.1%	2,247	0.9%	2,248.7	5.7%
6 – Minor Collector	616	13.6%	24,111	9.9%	3,671.9	9.3%
7 - Local	694	15.3%	21,892	9.0%	29,374.5	74.4%
Not Available	0	0.0%	5	<0.1%	-	-
Total	4,528	100.0%	243,884	100.0%	39,476.7	100.0%

Source: 2015-2019 Crash Data obtained from NDOT. Functional Class roadway data obtained from NDOT.



Source: 2015-2019 Crash Data obtained from NDOT. Functional Class roadway data obtained from NDOT.

Figure 23 – Pedestrian Crashes and Overall Crashes by Functional Classification

Pedestrian crashes by speed limit are shown in **Table 7**. While the percent of crashes for overall crashes and pedestrian crashes are largely similar based upon speed limit, there are some differences. For example, 37% of pedestrian crashes occur along roadways in Nevada with a speed limit of 30-39 miles per hour versus 23% when compared to all crashes along the same roads. In contrast, 21% of all crashes occur along roadways with a speed limit of 60-69 miles per hour, but only 2% of pedestrian crashes occur along the same roadways. This is likely due to the fact that by state law, pedestrians are not allowed on Interstates, which generally fall within this speed limit.

Table 7 – Pedestrian Crashes by Posted Speed Limit

Speed Limit	Pedestrian		Total	
	Crashes	%	Crashes	%
<= 20 MPH	11	0.24%	290	0.1%
21 - 29 MPH	294	6.49%	8,693	3.6%
30 - 39 MPH	1,684	37.19%	56,462	23.2%
40 - 49 MPH	1,515	33.46%	74,149	30.4%
50 - 59 MPH	257	5.68%	18,299	7.5%
60 - 69 MPH	93	2.05%	51,147	21.0%
70+	33	0.73%	9,659	4.0%
Not Available	641	14.16%	25,185	10.3%
Total	4,528	100.00%	243,884	100.0%

Source: 2015-2019 Crash Data obtained from NDOT. Speed Limit data obtained from NDOT.

Not surprisingly, pedestrian crashes are most common in urban areas, as shown in **Table 8.** However, there is a skew in rural areas towards pedestrian crashes being more severe. While only 2% of pedestrian crashes occur in rural areas, 7% of fatal pedestrian crashes occur in rural areas.

Table 8 – Pedestrian Urban and Rural Crashes

	Fatal Pedestrian		Serious Injury Pedestrian		Total Pedestrian	
	Crashes	%	Crashes	%	Crashes	%
Urban Crashes	336	92.82%	687	97.45%	4,430	97.84%
Rural Crashes	26	7.18%	18	2.55%	98	2.16%
Total Pedestrian Crashes	362	100.00%	705	100.00%	4,528	100.00%

Sources: 2015-2019 Crash Data obtained from NDOT, US Census Bureau - 2020 Geography Data.

According to the National Association of City Transportation Officials[1], pedestrian peak hours typically occur around noon/lunchtime. However, based on **Table 9**, almost half (45%) of Nevada pedestrian crashes occur during dark conditions. Over 41% of pedestrian crashes occur during dark conditions with some amount of lighting (spot lighting or continuous lighting).

[1] https://nacto.org/publication/urban-street-design-guide/design-controls/design-hour/

Table 9 – Pedestrian Crashes by Lighting Condition

Lighting Condition		Pedestrian Crashes	Percent
Dawn		80	1.77%
Daylight		2,196	48.50%
Dusk		112	2.47%
Dark	Dark - No Lighting	139	3.07%
	Dark - Spot Lighting	696	15.37%
	Dark - Continuous Lighting	1,182	26.10%
	Dark - Unknown Lighting	24	0.53%
Other/Unknown		99	2.19%
Total		4,528	100.00%

Source: 2015-2019 Crash Data obtained from NDOT.

Table 10 shows pedestrian crashes in Nevada by roadway geometry. As shown, over 60% of pedestrian crashes occur along segments of roadway without a curve and not at an intersection.

Table 10 – Pedestrian Crashes by Roadway Geometry (Functional Classes 1-6)

	Pedestrian		Total	
	Crashes	%	Crashes	%
Segment	2,738	60.47%	18,021	7.4%
Intersection	1,528	33.75%	148,583	60.9%
Curve	262	5.79%	55,383	22.7%
Not available	0	0.00%	5	0.0%
Total	4,528	100.00%	243,884	100.0%

Source: 2015-2019 Crash Data obtained from NDOT. Curves were not available for Functional Class 7.

6.3.1. Pedestrian Crash Rates

Table 11 presents pedestrian crash rates based on posted speed limits of roadways within Nevada. Overall pedestrian crash rates generally decrease per hundred million vehicle miles traveled as the speed of the roadway increases, with an extremely small rate of pedestrian crashes on roadways with speed limits at or above 60 miles per hour. However, when looking only at fatal pedestrian crash rates, there is an increase in the pedestrian fatality rate on roadways with speed limits between 21-39 miles per hour, with the highest fatal pedestrian crash rates occurring on roadways with speed limits between 30-39 miles per hour.

Table 11 – Pedestrian Crash Rate per HMVMT by Posted Speed Limit

Speed Limit	Pedestrian Crash Rates per HMVMT	
	Total Pedestrian	Fatal Pedestrian
<= 20 MPH	26.694	0.000
21 - 29 MPH	9.876	0.370
30 - 39 MPH	7.126	0.449
40 - 49 MPH	3.190	0.296
50 - 59 MPH	1.273	0.275
60 - 69 MPH	0.076	0.009
70+	0.072	0.038
Total	1.396	0.124

Source: 2015-2019 Crash Data obtained from NDOT. Speed Limit data obtained from NDOT. Due to a combination of incomplete network data for speed limit and AADT data, the crash rates were calculated using a subset of the total pedestrian crashes throughout the state.

Table 12 shows the pedestrian crash rates on roadways in Nevada by functional classification. While functional class 5 roadways have lower crash rates, there are very few functional class 5 roadways in Nevada. Aside from functional class 5 roadways, the overall pedestrian crash rates generally increase as the functional class of the roadway increases. When looking at the fatal pedestrian crash rate, there is a higher rate among roadways with a functional class of 3 and 4. Many of these roadways involve higher speed limits that result in more severe outcomes for pedestrians in the event of a crash.

Table 12 – Pedestrian Crash Rate per HMVMT by Functional Classification

Functional Classification	Total Pedestrian	
	Total Pedestrian	Fatal Pedestrian
1 - Interstate	0.266	0.071
2 – Principal Arterial: Other Freeways / Expressways	0.179	0.011
3 – Principal Arterial: Other	3.796	0.465
4 – Minor Arterial	5.523	0.482
5 – Major Collector	0.289	0.048
6 – Minor Collector	5.880	0.345
7 - Local	4.748	0.177
Total	3.340	0.267

Source: 2015-2019 Crash Data obtained from NDOT. Functional Class roadway data obtained from NDOT. VMT data was derived from NDOT's Annual Vehicle Miles of Travel yearly reports. Functional Classification 5 roadways are uncommon in Nevada.

Table 13 shows the location of fatal pedestrian crashes by non-motorist location. Approximately two-thirds (65%) of pedestrian fatalities occurred at a non-intersection location along a roadway. Identifying the location of pedestrians in fatal pedestrian crashes requires the use of the FARS database (instead of NCATS). As such, there is a slight variation in the total number of pedestrian fatalities during the period 2015-2019.

Table 13 – Non-Motorist Location of Fatal Pedestrian Crashes

Non-Motorist Location	Fatal Crashes
Non-Intersection (On Roadway)	240
At Intersection (Marked Crosswalk)	67
Sidewalk	16
At Intersection (Not in Crosswalk)	10
Shoulder/Roadside	7
Unknown Location	7
At Intersection (Unmarked Crosswalk)	6
Driveway Access	4
Non-Intersection (Crosswalk)	4
Non-Trafficway Area	3
Non-Intersection (On Roadway, Crosswalk)	2
Other	2

Source: 2015-2019 Crash Data obtained from FARS.

6.3.2. Summary of Pedestrian Crash Data

In summary, about 45% of pedestrian crashes are occurring during dark conditions. Functional classification 3 and 4 roadways exhibit some of the highest fatal pedestrian crash rates per vehicle mile traveled, and account for 68% of pedestrian crashes in Nevada. Roadways with speed limits between 30 - 39 miles per hour exhibit the highest fatal pedestrian crash rates, and account for 37% of pedestrian crashes in Nevada. Pedestrian crashes in general are more fatal and severe than overall crashes. The results of this pedestrian crash data analysis indicate that there are certain conditions and roadways that experience a greater portion of pedestrian crashes, and a higher rate of fatal pedestrian crashes.

7. MID-BLOCK PEDESTRIAN TREATMENT HIERARCHY

7.1. Treatment Hierarchy

Pedestrian safety has been a major concern throughout the 140-year history the automobile, resulting in the development of numerous safety treatment options for mid-block pedestrian crossings. As noted in the introduction, these can broadly be divided into seven main categories: no treatment, unsignalized crossings, RRFBs, EABs, PHBs, three-color mid-block signals (MBS), and grade separations (GS).

In preparation for development of a treatment evaluation tool, the project team formalized a hierarchy of treatment options. The hierarchy is based on guidance developed by the Transportation Association of Canada, further adapted for US and Nevada practice. **Figure 24** shows the adapted treatment hierarchy.

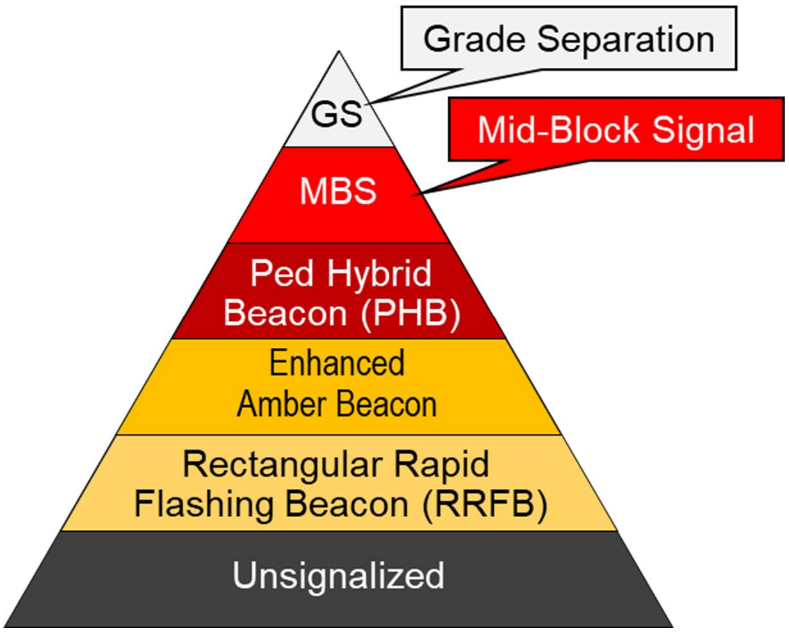


Figure 24 – Pedestrian Crossing Treatment Hierarchy

The Transportation Association of Canada appears to have been one of the first organizations to set out a clear hierarchy of pedestrian crossing treatments. In the Canadian guidance, as pedestrian and motorized traffic volumes grow and operational conditions become more complex, the treatment progresses from a marked but unsignalized crosswalk, to a crosswalk with RRFBs, to a crosswalk with RRFBs and overhead signs, to an enhanced crosswalk with overhead signs and large-diameter amber beacons (**Figure 21**), to a signalized mid-block crossing (MBS).

Although PHBs are not part of the Canadian hierarchy, they logically fit between the amber-beacon and signalized-crossing options, and are particularly suitable for high-speed roadways. While not specifically mentioned in the Canadian guidelines, grade separations (pedestrian overpasses and underpasses) feature prominently in the international research and some of the older American studies. They sit at the top of the hierarchy as a preferred treatment for sites with high traffic speeds or extremely heavy pedestrian or vehicular flows. An example is the set of four pedestrian overpasses at S Las Vegas Blvd and E Flamingo Road in Las Vegas, which connect major developments such as Caesars Palace and Bellagio.

7.2. RRFBs and EABs: Similarities and Differences

Rectangular Rapid Flashing Beacons (RRFBs) and Enhanced Amber Beacons (EABs) both provide flashing yellow lights intended to warn motorists of likely pedestrian presence. RRFBs are generally considered to be a lower level of treatment than EABs.

RRFBs were developed in the mid-2000s to reduce the cost of installing warning lights at mid-block pedestrian crossings. As shown in Figure 5 on Page 4, RRFBs typically have a pair of post-mounted rectangular signal heads. Occasionally they are augmented with a second set of lights mounted overhead (Figure 6 on Page 4). Wireless communication typically links the pedestrian pushbuttons to the control modules, and energy is usually supplied from solar panels, eliminating the need for underground wiring. As a result, RRFBs are usually simpler to install than the Enhanced Amber Beacon (EAB) design.

Although EABs are an older design, they are generally preferable for pedestrian crossings on multi-lane streets because they allow a beacon to be placed above each travel lane. EABs are typically mounted on mast arms (Figure 7Figure 6 on Page 4) or span wire (Figure 8 on Page 4). This allows each beacon head to be positioned centrally in the driver's field of view. In the Toronto configuration (Figure 8), a minimum of 4 circular heads are used, augmented by overhead signage identifying the crosswalk. EABs can be equipped with additional heads for wide crossings, such as crossings of multilane streets or locations where a trail crosses a street on a skew.

Visibility is influenced by the physical size of a visual target, its luminance (light output), and the level of contrast with its surroundings. Target size is a major difference between RRFBs and EABs: RRFB signal heads are considerably smaller. The MUTCD (FHWA 2023) currently stipulates a minimum size of 5 x 2 inches (10 square inches) for RRFB heads; one vendor's "extra-large" heads are 7 x 3 inches (21 square inches). In comparison, EAB signal heads typically have a diameter of 8 inches (50 square inches) or 12 inches (113 square inches). Backplates (usually black in color) can increase contrast between the beacon head and the sky. EABs allow the use of full-size backplates, but equipment vendors rarely supply backplates for RRFBs, perhaps due to the limited space between the lighting assembly and signage mounted on the same pole.

Some criteria for RRFB and EAB use are presented in current Canadian design guidance. For example, under certain combinations of traffic speed and volume, the Ontario Traffic Manual (MTO 2016) recommends using an RRFB if a median refuge is provided, and an EAB if there is no median refuge.

7.3. Pedestrian Treatment Enhancements

Most of the treatments identified in **Figure 24** can be enhanced by the addition of a median refuge (**Figure 18**). In addition, pedestrian crossings on low-speed roadways can be enhanced by the addition of a raised crosswalk which functions as a speed table to slow the approaching traffic (**Figure 25**).

Photo: Scott Batson/Wikimedia Commons

Figure 25 – An Unsignalized Raised Crosswalk in Portland, Oregon

7.4. Combined Hierarchy

Table 14 lists valid combinations of the treatment hierarchy and treatment enhancements. Pink shading identifies "red" treatments that include a signal phase where it is compulsory for motorists to come to a complete stop. Yellow shading identifies treatments which only provide warning of possible pedestrian presence.

In general, options at the bottom of the hierarchy are suitable for locations with low pedestrian and motor vehicle volumes and low speeds. Higher levels of treatment become necessary with increases in traffic speeds, motor vehicle volumes, or pedestrian volumes. Additional discussion of the combined hierarchy can be found in **Appendix A**.

Table 14 - Hierarchy of Pedestrian Treatments

6	**Grade Separation (GS)**
5bM	Mid-block signal with median refuge
5b	**Mid-block signal (MBS) – MUTCD Style**
5aM	Mid-block pedestrian signal with median refuge
5a	**Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style**
4M	Pedestrian hybrid beacon with median refuge
4	**Pedestrian hybrid beacon (PHB)**
3XM	Enhanced pedestrian-activated amber beacon with raised crosswalk and median refuge
3M	Enhanced pedestrian-activated amber beacon with median refuge
3X	Enhanced pedestrian-activated amber beacon with raised crosswalk
3	**Enhanced pedestrian-activated amber beacon (EAB)**
2XM	Rectangular rapid-flashing beacon (RRFB) with raised crosswalk and median refuge
2M	Rectangular rapid-flashing beacon (RRFB) with median refuge
2X	Rectangular rapid-flashing beacon (RRFB) with raised crosswalk
2	**Rectangular rapid-flashing beacon (RRFB)**
1XM	Unsignalized marked crossing with raised crosswalk and median refuge
1M	Unsignalized marked crossing with median refuge
1X	Unsignalized marked crossing with raised crosswalk
1	**Unsignalized marked pedestrian crossing (zebra crossing)**
0	No treatment

8. NEVADA PEDESTRIAN TREATMENT EVALUATION WORKBOOK

Utilizing the treatment hierarchy described in **Section 7**, the project team developed a Microsoft Excel based Nevada Pedestrian Treatment Evaluation Workbook. The workbook is intended to help practitioners select appropriate mid-block pedestrian treatments based on local site conditions. The workbook is derived from information gathered through the literature review. A copy of the workbook is included in **Appendix D**. A link to the workbook will be available online via NDOT once finalized.

Results from the workbook should be treated as guidance, since it does not account for factors that might result in the need for a higher treatment level such as visibility problems or the recurrent presence of intoxicated pedestrians.

The workbook's main worksheet combines two functions: treatment selection guidance and econometric (benefit/cost) analysis:

- **Treatment selection guidance**. The upper portion of the main worksheet provides a star rating (0 to 5 stars) based on user-supplied information such as the selected treatment, site characteristics like traffic speed, and the pedestrian and motorized traffic volumes. This portion of the worksheet also indicates the relative cost of the treatment on a scale of 1 to 5 dollar signs.
- **Econometric analysis.** The lower portion of the main worksheet performs a time series analysis to generate econometric results. These include the benefit/cost (B/C) ratio, Net Present Value (NPV), and when mathematically feasible, the Internal Rate of Return (IRR).

Separate worksheets (which could be locked or hidden from end users) perform supporting computations and store data such as the default costs of each treatment. This allows analytical parameters such as costing data and discount rates to be updated from time to time.

The econometric calculations use a combination of Nevada-specific data (such as pedestrian crash rates and vehicle-miles traveled) and national information (such as Crash Modification Factors and monetary valuation per crash by level of severity) to estimate benefits and costs for various mid-block pedestrian treatments. Both the up-front cost for installing the treatment and its ongoing operation and maintenance costs are taken into consideration. Default treatment cost values included in the workbook can be overridden by the user if more refined estimates are available.

8.1. Analysis Inputs and Outputs

8.1.1. User-Supplied Data

The Pedestrian Treatment Evaluation Workbook includes instructions on how to enter the user-supplied site characteristics, which include the following:

- Roadway type: Residential or collector street, urban/suburban arterial, rural highway, freeway/expressway
- Configuration: Undivided (no median) or divided (with median), number of lanes
- Speed: Posted roadway speed limit
- Average Daily Traffic (ADT): Motor vehicle traffic volume
- Pedestrians crossing per hour (estimated or observed)
- Pedestrian expansion factor: The ratio of total daily pedestrian crossings to crossings completed in the peak hour of pedestrian activity (a default value is embedded)

- Traffic growth rates (vehicle and pedestrians) (optional)
- Project completion year and month

8.1.2. Internal Computations

Separate sheets in the Excel workbook store default analytical parameters and complete various internal calculations. These include the following worksheets:

- Potential treatments and treatment enhancements table
- Economic analysis parameters table
- Economic analysis worksheet

8.2. Workbook Logic Overview

After site-specific data have been input by a user, the workbook will display potential crossing treatments for the location with accompanying star ratings and cost ranges. These functions are table lookups based on pre-established ratings stored in one of the behind-the-scenes worksheets.

8.2.1. Star Ratings

Suggested treatments (0 to 5 stars) are provided based on 61 combinations of the following inputs:

- Roadway type
- Divided or undivided
- Number of lanes
- Speed limit
- Exposure range

Star ratings for potential treatments can be interpreted as follows:

★ Marginally Recommended

★★ Weakly Recommended

★★★ Possibly Recommended

★★★★ Recommended

★★★★★ Highly Recommended

The star ratings displayed by the workbook were pre-determined by the project team in consultation with Nevada DOT and the TAC. Zero-star treatments are suppressed from the output; for example, if the user proposes to deploy an RRFB on a high-speed roadway, the worksheet does not display a star rating because this was determined to be an inappropriate environment for RRFB use.

8.2.2. Cost Range Ratings

The workbook displays the relative implementation cost for each treatment on a scale from 1 to 5 dollar signs. These ranges were predetermined by the project team in consultation with Nevada DOT and the TAC. For example, grade separation is designated as a $$$$$ treatment.

8.2.3. Actuarial Risk Model and Safety Benefit Computations

The Nevada Pedestrian Treatment Evaluation Workbook estimates site-specific safety benefits of the proposed for mid-block pedestrian treatment. These benefits are compared with the expected cost; results are expressed as the B/C ratio and net present value (NPV). Where mathematically feasible, the internal rate of return (IRR) is also displayed. (IRR is mathematically undefined in some cases, such as when the first-year benefits exceed the capital cost of the improvement).

The economic metrics are computed solely on the basis of the safety benefits of the treatment, and do not consider increases or decreases in pedestrian or vehicular delay resulting from the treatment. To accomplish this, the workbook applies a standard actuarial risk model to estimate the expected number of casualties of each severity level at the site (fatal, serious, and minor injuries). The actuarial model is based on the following core logic:

$$R = H \times E$$

Where:

R = Risk (expected number of pedestrian casualties)

H = Hazard to pedestrians (probability of a pedestrian casualty per unit of exposure)

E = Exposure (motorized traffic volume × pedestrian traffic volume)

Exposure data is supplied by the user as the site-specific pedestrian and vehicular volumes for the location where the pedestrian treatment will be installed. For ease-of-use, hazard is pre-computed based Nevada DOT vehicle-miles-traveled data, pedestrian crash counts from Nevada law enforcement reports, and pedestrian emergency department admissions estimates from the Centers for Disease Control & Prevention (CDC).

The estimated numbers of casualties at each severity level are multiplied by treatment-specific crash modification factors (CMFs) to estimate the expected changes in the number of casualties. The workbook then estimates the monetary benefits of pedestrian crash reduction using National Safety Council valuations per treatable exposure. These are then compared with the life-cycle costs of the treatment, which include the initial deployment cost and annual operation and maintenance costs.

8.3. Data Inputs and Outputs

The figures below illustrate the user inputs and outputs for the main worksheet, which is comprised of several tables. Throughout the main worksheet, cells shaded in yellow are for user input. Calculated values are displayed in the cells with light blue shading. In some cases, previous selections will cause a user input to appear or disappear depending on the information required for subsequent calculations.

8.3.1. Site Characteristics Table

The Site Characteristics table is shown in **Figure 26**. Inputs and outputs are explained below.

Lines 5-8 are headers. The information provided on these lines is for the user's convenience and does not affect the calculations.

Line 9: This line is used to select the roadway classification: residential/collector, urban arterial, rural highway, or freeway/expressway.

Line 10: Select the roadway configuration: undivided (no median) or divided (with median) An error message will appear if the combination of classification and configuration is not supported by the workbook.

1	**Nevada Pedestrian Treatment Evaluation Worksheet**		
2	Version 0.6		
3			
4		**Site Characteristics**	
5	Project Number	Site Description	
6	**VIP-1111**	**Main Street at First Avenue**	
7	Date	Analyst/Notes	
8	11-08-22	J. Doe	
9	Roadway Type		Urban/Suburban Arterial
10	Configuration		Undivided: 5 to 6 Lanes
11	Speed Range (mph)		40-45
12			
13	V: Motor Vehicle Volume - Annual Average Daily Traffic (AADT)		20,000
14	P: Pedestrians Crossing Per Hour (Peak Hour)*		30
15	X: Pedestrian eXpansion Factor		Default (10.0)
16	Expansion Factor	10.0	
17	PX: Pedestrian Crossings per Day		300
18	PXV: Vehicle-Pedestrian Exposures per Day		6,000,000
19			
20	Motor Vehicle Traffic Growth Rate		Default (2.0%)
21	Annual Growth Rate	2.0%	
22	Pedestrian Traffic Growth Rate		Default (3.0%)
23	Annual Growth Rate	3.0%	
24	* Observed pedestrian count or estimated count including increases due to improved pedestrian access. Highly vulnerable road users such as children, visually impaired people, and people with mobility impairment should be counted as double.		

Figure 26 – Site Characteristics Table

Line 11: Select the relevant roadway speed limit. An error message will appear if the combination of classification and speed limit is not supported by the workbook.

Line 13: Enter annual average daily traffic (motor vehicle traffic volume).

Line 14: Enter the typical number of pedestrians crossing the roadway during the peak hour of pedestrian activity. This could include an adjustment for latent demand, which occurs when existing difficult conditions suppress pedestrian activity. Highly vulnerable road users such as children, visually impaired people, and people with mobility impairment should be counted as double. (Pedestrians and motorized traffic should be counted on days that are representative of ordinary conditions).

Line 15: Select the pedestrian expansion factor from the drop-down menu. This is the ratio of total daily pedestrian crossings to crossings completed in the peak hour of pedestrian activity. There are two options: DEFAULT or CUSTOM.

- The default value of 10.0 is based on studies of typical pedestrian pushbutton actuations in Western US cities. If the user has local information, they can override the default with a custom value.
- If the user has a daily (rather than hourly) pedestrian count, they can enter it on Line 14 and set the expansion factor to 1.0 on Line 15.

Line 17 calculates and displays the total daily pedestrian volume Line 18 displays the pedestrian exposure, calculated as the product of daily vehicles × daily pedestrians.

Lines 20-23: Many areas of Nevada have been experiencing significant traffic growth over time. This is important to consider in the benefit/cost computations. Similar to the previous item, item there are two options: DEFAULT or CUSTOM. The default growth rate is 2.0% per year for vehicles and 3.0% per annum for pedestrians. Negative traffic growth rates, such as may be experienced in economically distressed areas, are allowed.

8.3.2. Growth Rate Computation Table

If the user has a forecast of the future motor vehicle or pedestrian volume and needs to compute the corresponding growth rate, a side calculation is available to the right of the main data entry area (**Figure 27**). Note that these rates are not automatically copied to the main calculations.

Optional Traffic Growth Rate Computation			
	Year	Daily Vehicles	Daily Peds
Current	2022	10,000	300
Future	2042	20,000	600
Annual Growth Rate		3.5%	3.5%
Note: Does not auto-populate the growth rates - values must be manually entered in cells B17 and B19.			

Figure 27 – Optional Growth Rate Computation Table

All growth rates are computed using the exponential compounding formula, $V_t=V_0(1+r)^t$ where V_0 is the current volume, V_t is the volume *t* years in the future, and *r* is the growth rate.

8.3.3. Potential Treatments & Treatment Enhancements Table

The Potential Treatments & Treatment Enhancements section of the spreadsheet (**Figure 28**) displays suggested pedestrian treatments based on the combination of roadway type, configuration, speed limit, and exposure supplied by the user on Lines 9-15. A total of 61 combinations are supported. Interpretations for the star ratings are as discussed in section 8.2.1.

26	Potential Treatments & Treatment Enhancements		
27	Star Rating	Treatment Description	Relative Cost
28	-		
29	☆	Unsignalized marked pedestrian crossing (zebra crossing)	$
30	☆☆☆	Rectangular rapid-flashing beacon (RRFB)	$$
31	☆☆☆☆	Enhanced pedestrian-activated amber beacon (EAB)	$$$
32	☆☆☆☆☆	Pedestrian hybrid beacon (PHB)	$$$$
33	☆☆☆☆☆	Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style	$$$$
34	☆☆☆☆☆	Mid-block signal (MBS) – MUTCD Style	$$$$
35	-		
36			
37	☆☆☆☆	[Treatment] + raised crosswalk	$$
38	☆☆☆☆	[Treatment] + median refuge	$$
39	☆☆☆☆☆	[Treatment] + raised crosswalk and median refuge	$$$

Figure 28 – Potential Treatments and Treatment Enhancements Table

8.3.4. Selected Treatment Table

The Selected Treatment table (**Figure 29**) allows the user to choose among seven pre-defined mid-block pedestrian safety treatments, or enter the information for a custom (user-defined) treatment.

Lines 45-47: Default values for up-front cost, annual maintenance cost, and service life are provided for the pre-defined treatments. If the user has site-specific or agency-specific cost or service life information they can override the defaults by selecting CUSTOM in the Project Cost drop-down menu (**Figure 30**).

41	Selected Treatment		
42	Treatment Type	Pedestrian Hybrid Beacon (PHB): Stand-Alone	
43			
44	Project Cost in 2022 dollars	Default	
45	Installation (one-time)	$300,000	
46	Maintenance & Ops (yearly)	$6,000	
47	Service Life (years)	25	
48	Crash Modification Factors	Default	
49	(0.00 = complete elimination of all crashes, 1.00 = no effect)		
50	Fatalities	0.54	
51	Serious Injuries	0.54	
52	Minor Injuries	0.54	
53			

Note: 0 star treatments are NOT automatically hidden from the drop-down on Line 42.

Figure 29 – Treatment Selection Table (Example 1)

41	Selected Treatment		
42	Treatment Type	Pedestrian Hybrid Beacon (PHB): Stand-Alone	
43			
44	Project Cost in 2022 dollars	Custom	
45	Installation (one-time)	==>	$10,000
46	Maintenance & Ops (yearly)	==>	$1,000
47	Service Life (years)	==>	20
48	Crash Modification Factors	Default	
49	(0.00 = complete elimination of all crashes, 1.00 = no effect)		
50	Fatalities	0.54	
51	Serious Injuries	0.54	
52	Minor Injuries	0.54	
53			

Figure 30 – Treatment Selection Table (Example 2)

Lines 50-52: Default crash modification factors are provided for each of the pre-defined treatments. Ordinarily these should not be modified, but it is possible to do so by selecting CUSTOM (**Figure 31**). If the user overrides the defaults, they should be sure to use CMFs that apply to PEDESTRIAN crashes, not "all" crashes.

Line 53: If a custom CMF is entered, describe how the CMF was determined.

41	Selected Treatment		
42	Treatment Type	Pedestrian Hybrid Beacon (PHB): Stand-Alone	
43			
44	Project Cost in 2022 dollars	Custom	
45	Installation (one-time)	==>	$10,000
46	Maintenance & Ops (yearly)	==>	$1,000
47	Service Life (years)	==>	20
48	Crash Modification Factors	Custom	
49	(0.00 = complete elimination of all crashes, 1.00 = no effect)		
50	Fatalities	==>	0.60
51	Serious Injuries	==>	0.60
52	Minor Injuries	==>	0.60
53	Describe CMF Source ==>		

Figure 31 – Treatment Selection Table (Example 3)

By selecting CUSTOM treatment type on Line 42, a completely customized cost and CMF profile can be entered (**Figure 32**).

41	Selected Treatment		
42	Treatment Type	Custom	
43	Description ==>		
44	Project Cost in 2022 dollars	Custom	
45	Installation (one-time)	==>	$10,000
46	Maintenance & Ops (yearly)	==>	$1,000
47	Service Life (years)	==>	20
48	Crash Modification Factors	Custom	
49	(0.00 = complete elimination of all crashes, 1.00 = no effect)		
50	Fatalities	==>	0.60
51	Serious Injuries	==>	0.60
52	Minor Injuries	==>	0.60
53	Describe CMF Source ==>		

Figure 32 – Treatment Selection Table (Example 4)

8.3.5. Economic Analysis Parameters Table

The Economic Analysis Parameters table (**Figure 33**) allows entry of site-specific project timing information and displays the econometric parameters that are automatically populated based on data stored in other sheets of the workbook.

Line 56: Enter the year when the project is expected to be completed.

Line 57: Enter the month of the year when the project is expected to be completed.

55	Economic Analysis Parameters		
56	Project Completion Year		2023
57	Project Completion Month		June
58	Base Year for Economic Computations		2022
59	Real discount rate for future-year benefits and costs		1.07%
60			
61	2022 Total costs per exposure		$0.0120
62	From fatalities	$0.0091	
63	From serious injuries	$0.0018	
64	From minor injuries	$0.0010	
65			
66	Pre-intervention Annual Pedestrian Casualty Risk		$71,807
67	From fatalities	$54,804	
68	From serious injuries	$10,747	
69	From minor injuries	$6,257	
70			
71	Post-intervention Annual Pedestrian Casualty Risk		$43,084
72	From fatalities	$32,882	
73	From serious injuries	$6,448	
74	From minor injuries	$3,754	
75			
76	First-Year Change in Pedestrian Risk (negative values indicate improved ped safety)		-$28,723

Figure 33 – Economic Analysis Parameters Table

All other computations in the Economic Analysis Parameters table are automatic.

Line 58 displays the time-basis for the economic calculations. This is usually the current year, unless a different value has been selected by the spreadsheet administrator.

Line 59 displays the "real" discount rate used in economic analysis computations. To avoid the need to forecast inflation, the spreadsheet works in constant dollars for the base year displayed on Line 57. As a result, the "real" discount rate simply reflects the fact that all other things being equal, it is preferable to get the benefits of a project sooner rather than later.

Lines 61-64 display the comprehensive economic costs of pedestrian casualties per exposure (also see Line 18).

Lines 66-69 compute the monetized annual pedestrian risk for the existing situation by multiplying the economic impact per exposure by the number of annual exposures (based on the data supplied by the user on Lines 9-11).

Lines 71-74 compute the modified exposure that will occur upon implementation of the pedestrian treatment, by multiplying the values from Lines 67-69 by the corresponding CMFs.

Line 76 computes the monetary value of the change in crash risk by subtracting Line 71 from Line 66. If the treatment reduces casualties (i.e., has a CMF less than 1), this value will be negative.

8.3.6. Economic Analysis Results Table

The Economic Analysis Results Table (**Figure 34**) displays the benefits and costs of the project. The spreadsheet calculates costs and benefits for each year of the project's service life, up to a total of 50 years. These computations are performed in **Lines 79-132.** The end-of-life salvage value is assumed to be zero.

By clicking the + or - buttons on the far left side of the worksheet, the results for individual years can be displayed or hidden for two blocks of 25 years each.

Usually the benefits will be increasing over time because of growth in pedestrian and motor vehicle traffic. Similarly, the costs will usually be decreasing over time because the value of future benefits and costs is discounted at the rate shown on Line 59.

Line 134 *displays the benefit/cost ratio. If this number is greater than 1, the project is cost-effective in reducing pedestrian casualties. A higher value is better, but small differences between competing projects should not be overemphasized.*

Line 135 displays the Net Present Value. This is the difference between the total benefits over the project's service life and the total costs over that duration. A higher value is better.

Line 136 displays the Internal Rate of Return (IRR) for the project, if it can be calculated. This is essentially the annual percent return on investment over the life of the project. IRR is undefined in some cases. For example, IRR cannot be computed if the first-year benefit exceeds the first-year cost (the return-on-investment goes to infinity and a #NUM! error message is displayed).

78	Economic Analysis Results		
79	Year	Benefits	Costs
80	2023	$14,208	$10,388
81	2024	$29,855	$989
82	2025	$31,031	$979
83	2026	$32,254	$968
84	2027	$33,524	$958
85	2028	$34,845	$948
86	2029	$36,218	$938
87	2030	$37,645	$928
88	2031	$39,128	$918
89	2032	$40,670	$908
90	2033	$42,273	$898
91	2034	$43,938	$889
92	2035	$45,669	$879
93	2036	$47,469	$870
94	2037	$49,339	$861
95	2038	$51,283	$851
96	2039	$53,304	$842
97	2040	$55,404	$833
98	2041	$57,587	$825
99	2042	$59,856	$816
100	2043	$62,214	$807
101	2044	$0	$0
102	2045	$0	$0
103	2046	$0	$0
104	2047	$0	$0
105	2048	$0	$0
106	<==Click to Expand		
132	**Totals in 2022 dollars**	**$897,714**	**$28,294**
133			
134	**Benefit/Cost Ratio**		**31.7**
135	Net Present Value		$869,421
136	Internal Rate of Return		#NUM!

Figure 34 – Economic Analysis Results Table

9. MICROSIMULATION MODELING AND SIGNAL TIMING ANALYSIS

This section describes the project team's work to assess the effects of nearly 200 combinations of mid-block pedestrian crossing design, signal timing strategy, pedestrian traffic demand, and vehicular traffic demand. The key performance measures were pedestrian and motorist delays.

Analysis was performed for two corridors with differing traffic volumes and geometric configurations, representing two sets of traffic conditions typical for the greater Las Vegas area. The analyses were performed using corridor microsimulation models, supported by corridor signal timing optimization models. They are theoretical in the sense that while the actual corridor geometrics were modeled, the pedestrian and motorized traffic volumes and signal timing plans were varied to stress the models and identify parameter combinations likely to result in excessive delay or, in the most extreme cases, gridlock.

The microsimulation modeling was completed with Vissim software (PTV 2023) and signal timing optimization was completed with Synchro Studio (Cubic Transportation Systems 2023). Relevant technical limitations of the Vissim software were discussed with NDOT and the technical advisory committee, resulting in the following decisions:

- RRFBs were modeled using the Vissim "priority rules" function. Specifically, the model was configured so that vehicles yield to pedestrians approaching from the left for the entire time they are crossing the street, and vehicles yield to pedestrians approaching from the right until they reach the median. NDOT reported that this is consistent with the observed driver behavior in Nevada. Since the rules of the road are encoded in the software, all modeled vehicles yield to pedestrians.
- PHBs were modeled as mid-block signals using timing plans that closely mimic PHB operations.

The analysis for each corridor included 90 combinations of the following variables:

- Pedestrian beacon type (RRFB vs PHB)
- Signal timing strategy (isolated vs coordinated)
- Presence or absence of a median refuge (one-stage vs two-stage pedestrian crossing)
- Vehicular volume
- Pedestrian volume

Delay was defined as the difference between the travel time with all traffic-related phenomena (including stopping at traffic signals and mid-block pedestrian crossings) and the free-flow travel time in the absence of any need to stop or slow for conflicting traffic.

9.1. Corridors Selected for Analysis

Two analysis corridors were selected in consultation with Nevada DOT and the Technical Advisory Committee, both in the Las Vegas area:

- **N. Martin Luther King (MLK) Boulevard from W. Vegas Drive / W. Owens Avenue to W. Carey Avenue (1 mile).** This high-volume corridor has three travel lanes in each direction separated by a median. The site includes the Judge J.B. Brooks Pedestrian Crosswalk, which is essentially the extension of the T-intersection with W. Bartlett Avenue. The Judge Brooks Crosswalk is located near the midpoint between the signalized intersections at W. Balzar Avenue and W. Carey Avenue. Land use along the corridor includes commercial properties, single-family residences, townhouses, and schools. Land use near the Judge Brooks Crosswalk is single-family residential to the east and school/institutional to the west.

- **E. Bonanza Road from N. Maryland Parkway to N. Eastern Avenue (0.8 miles).** This moderately-high-volume corridor has two travel lanes in each direction separated by a two-way left turn lane (TWLTL). A hypothetical pedestrian crossing was modeled as the extension of N. 23rd Street, located approximately two-thirds of the distance from the signalized intersection at N. Bruce Street to the signalized intersection at N. Eastern Avenue. Land use along the corridor includes single-family and multi-family residential buildings, with retail development at the east end of the corridor near the Bonanza and Eastern intersection.

The characteristics of the two corridors are summarized in **Table 15**.

Table 15 – Characteristics of Modeled Corridors

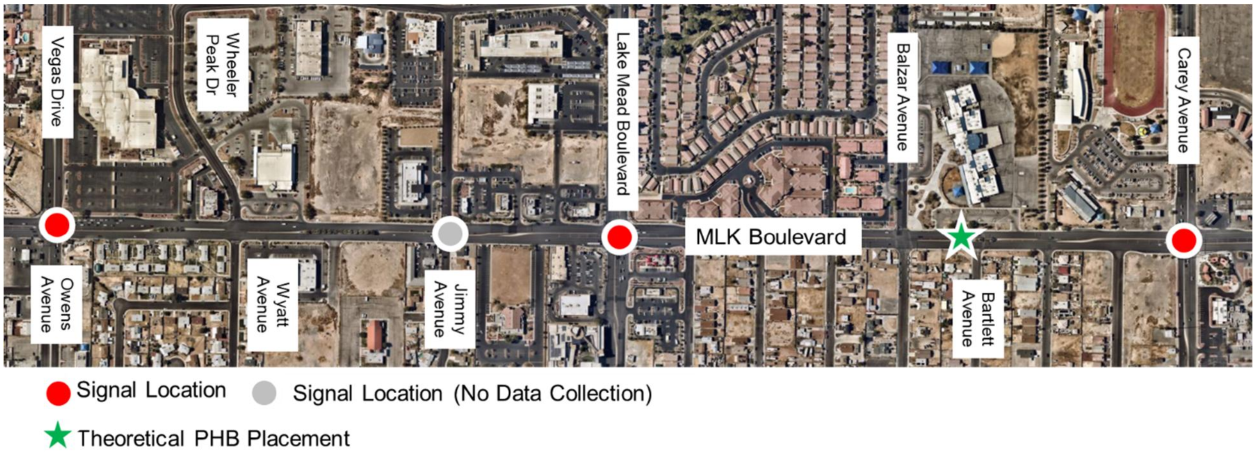
<table>
<tr><td colspan="2">N. Martin Luther King (MLK) Boulevard
W. Vegas Drive / W. Owens Avenue
to W. Carey Avenue

Image: Google Earth</td><td colspan="2">E. Bonanza Road
N. Maryland Parkway to N. Eastern Avenue

Image: Google Earth</td></tr>
<tr><td>Length</td><td>1 mile</td><td>Length</td><td>0.8 miles</td></tr>
<tr><td>Class</td><td>Urban/suburban arterial</td><td>Class</td><td>Urban/suburban arterial</td></tr>
<tr><td>Configuration</td><td>Divided</td><td>Configuration</td><td>TWLTL</td></tr>
<tr><td>Lanes</td><td>3 per direction</td><td>Lanes</td><td>2 per direction + TWLTL</td></tr>
<tr><td>Speed Limit</td><td>35 mph</td><td>Speed Limit</td><td>35 mph</td></tr>
<tr><td>AADT</td><td>40,500</td><td>AADT</td><td>19,550</td></tr>
<tr><td>Land Use</td><td>Commercial, residential, institutional (schools)</td><td>Land Use</td><td>Residential, retail</td></tr>
<tr><td>Notes</td><td>School zone</td><td>Notes</td><td>Major bus route</td></tr>
</table>

9.1.1. Martin Luther King Boulevard

The Martin Luther King Boulevard (**Figure 35**) segment was selected due to its high traffic volumes, multilane configuration (three through lanes in each direction), and the presence of an existing RRFB at the Judge J.B. Brooks Crosswalk near Booker Elementary School. The Judge Brooks Crosswalk is approximately halfway between two traffic signals, and is an extension of the T-intersection at Martin Luther King Boulevard and Bartlett Avenue. **Figure 36** provides a more detailed satellite view of the Judge Brooks Crosswalk, while **Figure 37** and **Figure 38** show the street view approaching it.



Base map: Google Earth

Figure 35 – Locations for the Martin Luther King Boulevard and Judge J.B. Brooks Crosswalk

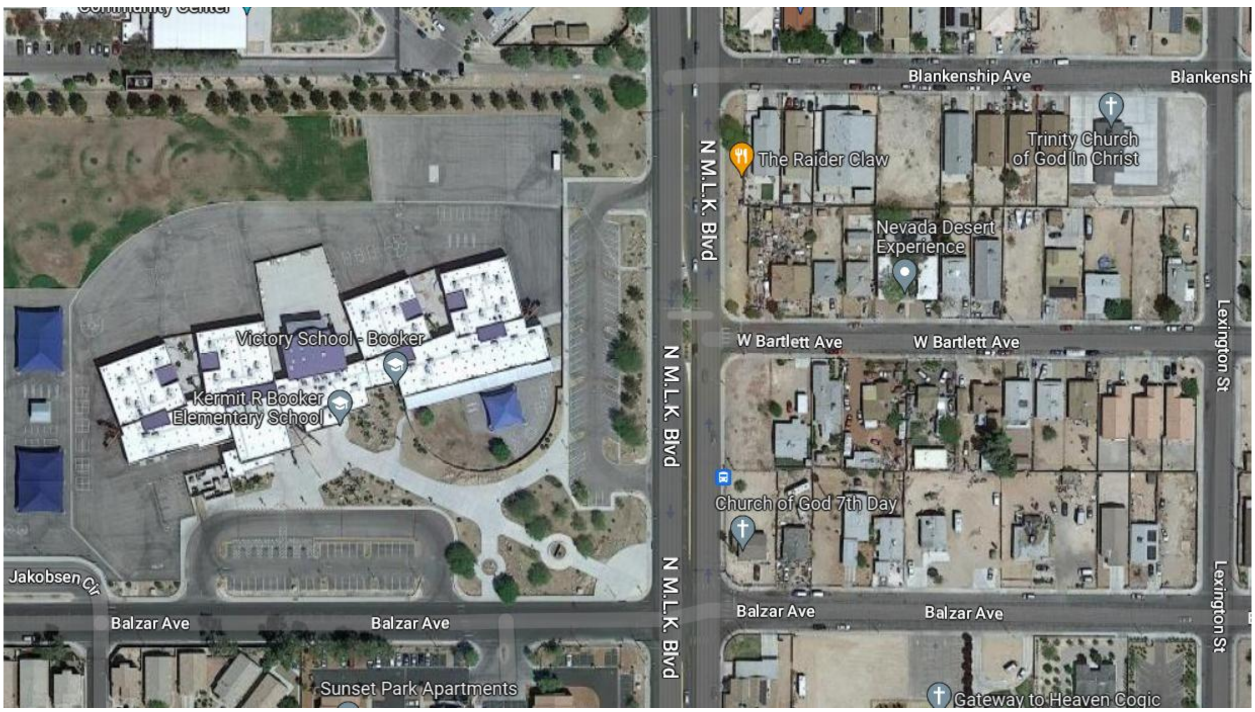


Image: Google Earth

Figure 36 – Aerial View of the Martin Luther King Boulevard and Judge J.B. Brooks (Bartlett Avenue) Crossing

Image: Google Street View

Figure 37 – Martin Luther King Boulevard and Judge J.B. Brooks Crosswalk Facing North (Bartlett Street to the right)

Image: Google Street View

Figure 38 – Martin Luther King Boulevard and Judge J.B. Brooks Crosswalk Facing South (Bartlett Street to the left)

9.1.2. Bonanza Road and 22nd Street

The Bonanza Road corridor (**Figure 39**) was selected for analysis because it was a recommendation from the NDOT Bonanza Road Safety Management Plan (December 2021). The modeled crossing at N. 22nd Street also serves as an example of a location where the pedestrian signal is asymmetrically spaced between two traffic signals.

Figure 39 – Bonanza Road Corridor

Bonanza Road has two through lanes in each direction with a two-way left-turn lane (TWLTL) and on-street parking. There is an existing painted crosswalk and signs on the east side of the 23rd Street intersection, but no existing crosswalk markings at the T-intersection with 22nd Street (**Figure 40**). **Figure 41** and **Figure 42** show the street view approaching each side of the crosswalk on Bonanza Road.

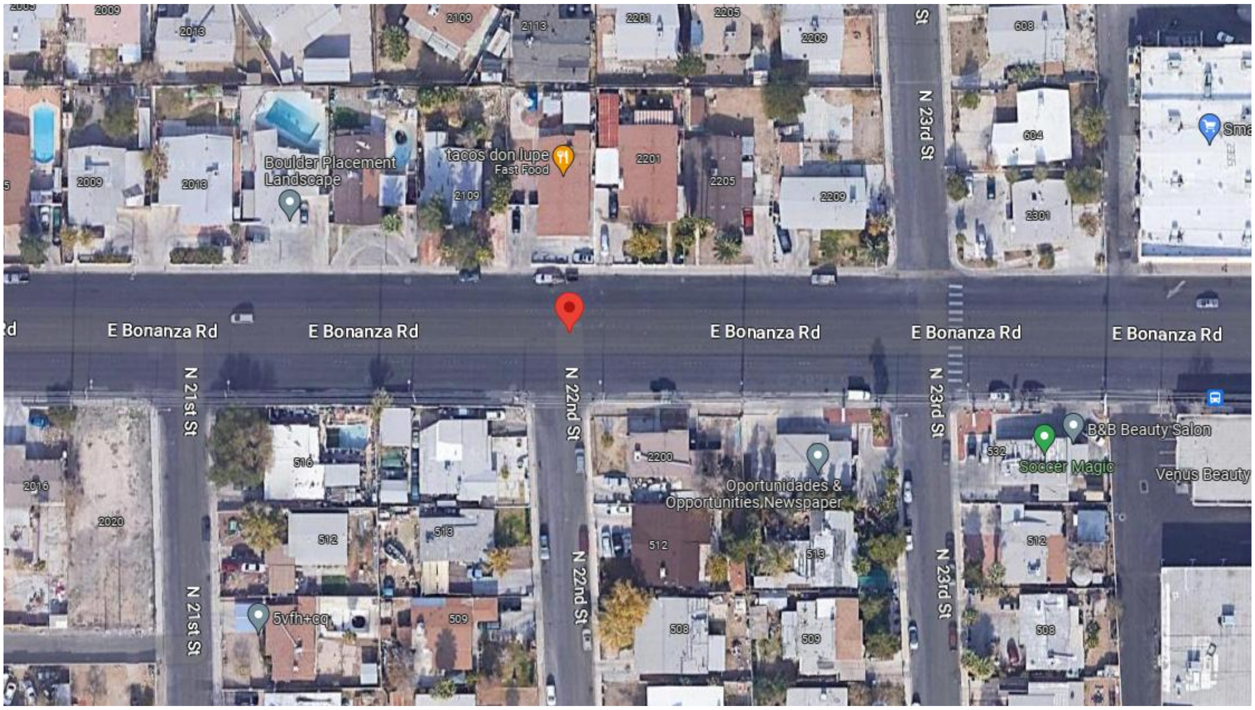


Image: Google Earth

Figure 40 – Aerial View of Bonanza Road and 22nd Street Crossing

Image: Google Street View

Figure 41 – Bonanza Road and 22nd Street Facing East

Image: Google Street View

Figure 42 – Bonanza Road and 22nd Street Crossing Facing West

9.1.3. Traffic Data Collection

Traffic volume counts for the N. Martin Luther King Boulevard and E. Bonanza Road corridors were conducted on Tuesday May 10, 2022, Wednesday May 11, 2022, and Thursday May 12, 2022. Video was recorded using MioVision cameras and post-processed to obtain AM and PM peak hour counts for the following intersections:

- N. Martin Luther King Boulevard at:
  - W. Vegas Drive / W Owens Avenue
  - W. Lake Mead Boulevard
  - W. Balzar Avenue (pedestrian count)
  - W. Carey Avenue
- E. Bonanza Road at:
  - N. Maryland Parkway
  - N. Bruce Street
  - N. 23rd Street (pedestrian count)
  - N. Eastern Avenue

9.1.3.1. Martin Luther King Boulevard

Turning movement counts were collected during the AM peak (7:00 AM – 9:00 AM) and afternoon peak (2:00 PM – 4:00 PM) periods at three signalized intersections with Martin Luther King Boulevard: Cary Avenue, Lake Mead Boulevard, and Owens Avenue/Vegas Drive. Additionally, pedestrians were counted at the Judge Brooks Crossing/Bartlett Avenue and at the intersection of Martin Luther King Boulevard and Balzar Avenue. For these pedestrian counts an earlier afternoon peak was chosen to capture the Booker Elementary School class hours which end at 2:15 PM.

The Martin Luther King Boulevard corridor also includes a signalized intersection at Jimmy Avenue/Mount Mariah Drive (located between Lake Mead Boulevard and Owens Avenue/Vegas Drive). This signalized intersection was not counted due to the low vehicular volume on the minor approaches, which were not expected to have any significant effect on the corridor timing or traffic delays.

9.1.3.2. Bonanza Road

Turning movement counts during the AM peak (7:00 AM – 9:00 AM) and PM peak (4:00 PM – 6:00 PM) periods were collected at the following intersections with Bonanza Road: Maryland Parkway, Bruce Street, and Eastern Avenue. Additionally, pedestrians were count at the Bonanza Road and 23rd Street crosswalk.

Turning movement volumes for both corridors were cross-checked with mainline counts published on the City of Las Vegas and Nevada DOT websites.

9.1.4. Geometric and Signal Timing Data

Roadway geometrics for the two corridors were obtained by building the Vissim models on satellite images from Google Earth. Google Street View and Bing Maps were used as additional references for coding the location, length, and permitted movements at turning lanes and similar features.

Existing traffic signal timing plans were obtained from the Regional Transportation Commission of Southern Nevada. Notably, the peak hour signal timings for both corridors are constrained by a predetermined cycle length intended to support four-way signal coordination across much of the greater Las Vegas region.

9.1.5. Nevada Pedestrian Treatment Evaluation Workbook Results

9.1.5.1. Martin Luther King Boulevard

The project team analyzed the Martin Luther King Boulevard and Judge Brooks Crosswalk using the Nevada Pedestrian Treatment Evaluation Workbook discussed in Section 8. Inputs used in the Treatment Selection Workbook were as follows:

- Urban/suburban arterial
- Divided, 6 lanes
- 35 MPH speed limit
- 40,500 ADT
- 13 pedestrian crossings in the peak hour
- Pedestrian expansion factor of 10
- Vehicle growth rate of 2%
- Pedestrian growth rate of 3%

Based on inputs for this location, five potential treatments and treatment enhancements were recommended from the selection workbook. **Table 16** shows the potential treatments for the Martin Luther King Boulevard at the Judge Brooks Crosswalk.

Table 16 – Potential Treatments for MLK Boulevard at Judge Brooks Crosswalk

Star Rating	Treatment Description	Relative Cost
☆	Enhanced pedestrian-activated amber beacon (EAB)	$$$
☆☆☆☆☆	Pedestrian hybrid beacon (PHB)	$$$$
☆☆☆☆	Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style	$$$$
☆☆☆☆☆	Mid-block signal (MBS) – MUTCD Style	$$$$
☆☆☆☆☆	Grade Separation (GS)	$$$$$
☆☆☆☆☆	[Treatment] + Median Refuge	$$

Benefit/cost ratios for the RRFB and Enhanced Amber Beacon treatments for this location are shown in **Table 17**. Although the results show the Enhanced Amber Beacon (EAB) is the most cost-effective treatment, the very high benefit/cost ratio and low star rating for the EAB suggest a pedestrian hybrid beacon is likely to be the most satisfactory treatment for this site. In either case, the analysis suggests the addition of a median refuge is highly recommended if the available road space is sufficient to accommodate one.

Table 17 – Treatment Selection Workbook Results for MLK Boulevard at Judge Brooks Crosswalk

Treatment	PHB (Stand-Alone)	PHB (Integrated)	Enhanced Amber Beacon
Star Rating	☆☆☆☆☆	☆☆☆☆☆	☆
Benefit-Cost Ratio	2.9	2.5	38.2

9.1.5.2. Bonanza Road

The team used the Nevada Pedestrian Treatment Evaluation Workbook to analyze the Bonanza Road and 22nd Street crossing. Pedestrian volumes were based on those observed at 23rd Street. Compared to the MLK site, this location has lower motorized traffic volumes but higher pedestrian volumes, resulting in more pedestrian exposure overall. Compared to MLK, crossing Bonanza Road requires less physical effort for pedestrians because there are fewer lanes.

Inputs used in the Treatment Selection Workbook for the location include:

- Urban/suburban arterial
- Undivided, 5 to 6 lanes
- 35 MPH speed limit
- 19,550 ADT
- 48 pedestrian crossings in the peak hour
- Pedestrian expansion factor of 10
- Vehicle growth rate of 2%
- Pedestrian growth rate of 3%

Based on inputs for this location, five potential treatments and treatment enhancements were recommended from the selection workbook. **Table 18** shows the potential treatments and the corresponding star and relative cost ratings.

Table 18 – Potential Treatments for Bonanza Road at 22nd Street

Star Rating	Treatment Description	Relative Cost
☆	Enhanced pedestrian-activated amber beacon (EAB)	$$$
☆☆☆☆☆	Pedestrian hybrid beacon (PHB)	$$$$
☆☆☆☆	Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style	$$$$
☆☆☆☆☆	Mid-block signal (MBS) – MUTCD Style	$$$$
☆☆☆☆☆	Grade Separation (GS)	$$$$$
☆☆☆☆☆	[Treatment] + Median Refuge	$$

Benefit/cost ratios for the RRFB and Enhanced Amber Beacon treatments for the Bonanza Road and 22nd Street location are shown in **Table 19**. As at MLK, although the results show the Enhanced Amber Beacon (EAB) is the most cost-effective treatment, the extraordinarily high benefit/cost ratio and low star rating for the EAB indicate a PHB is likely to be the most satisfactory treatment for this site. In either case, the analysis suggests the addition of a median refuge is highly recommended if one will fit in the available road space.

Table 19 – Treatment Selection Workbook Results for Bonanza Road at 22nd Street

Treatment	PHB (Stand-Alone)	PHB (Integrated)	Enhanced Amber Beacon
Star Rating	☆☆☆☆☆	☆☆☆☆☆	☆
Benefit-Cost Ratio	5.2	4.4	68.0

9.2. Corridor Modeling with Vissim and Synchro

To assess the effects of the mid-block pedestrian crossing design and signalization strategy on motorist and pedestrian delays, the project team prepared an extensive family of microsimulation models for the Martin Luther King Boulevard and Bonanza Road Corridors. Signal timing was optimized for both corridors using Synchro Studio 11 software (Cubic Transportation Systems 2023) and corridor modeling was completed with PTV Vissim 2023 (PTV 2023). In all, 180 scenarios (combinations of geometrics, signalization, and volumes) were analyzed with Vissim, 90 for each corridor.

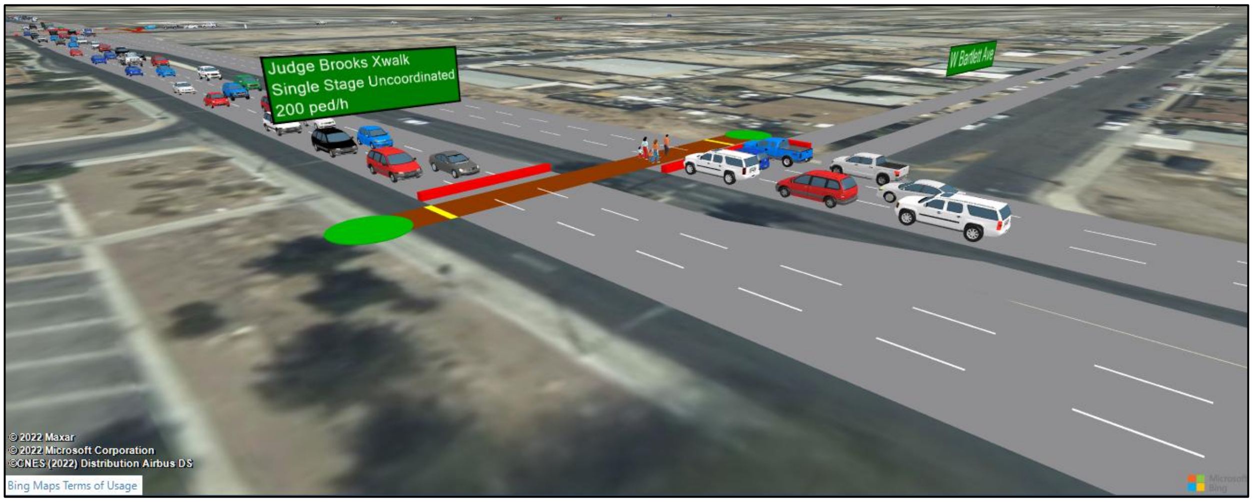


Figure 43 – Vissim Model of Martin Luther King Boulevard at the Judge J.B. Brooks Crosswalk

9.2.1. Scope

Martin Luther King Boulevard. A particular focus of the modeling for the MLK corridor was the existing Judge J.B. Brooks Pedestrian Crossing (**Figure 43**). This pedestrian crossing is an extension of the T-intersection with W. Bartlett Avenue, about one block north of Kermit R. Booker Elementary School. In the field, the crossing is currently equipped with a rectangular rapid flashing beacon (RRFB). This crossing is located about halfway between two signalized intersections, namely MLK and W. Lake Mead Boulevard, and MLK and W. Carey Avenue.

Bonanza Road. For the Bonanza corridor, a pedestrian crossing was modeled at N. 22nd Avenue as the extension of the existing T-intersection. In the field, a marked, unsignalized pedestrian crossing exists one block to the east at N. 23rd Avenue. The modelled location was moved because N 23rd Avenue is a four-leg intersection on a TWLTL, resulting in design complications under the hypothetical two-stage pedestrian crossing configuration, particularly for road users approaching or crossing minor legs when the PHB is dark. At this site, the spacing between the pedestrian crossing and the adjacent signalized intersections is asymmetrical.

For each corridor, six traffic control combinations were analyzed:

- Rectangular rapid flashing beacon without median refuge (single-stage pedestrian crossing)
- Rectangular rapid flashing beacon with median refuge (two-stage pedestrian crossing)
- Isolated (stand-alone) pedestrian hybrid beacon (PHB) without median refuge
- Coordinated pedestrian hybrid beacon (PHB) without median refuge
- Isolated pedestrian hybrid beacon (PHB) with median refuge
- Coordinated pedestrian hybrid beacon (PHB) with median refuge

In this context, “coordinated” means the phasing and timing of the PHB are linked to the upstream and downstream signals, while “isolated” or “stand-alone” means the PHB signal controller is not coordinated, and is responsive only to pedestrian pushbutton actuations. Traffic signal coordination facilitates the progression of motor vehicle platoons along corridors through synchronization of traffic signal controllers at adjacent intersections. More advanced installations also exchange data such as the amount of time required for platoons to clear (**Figure 44**).

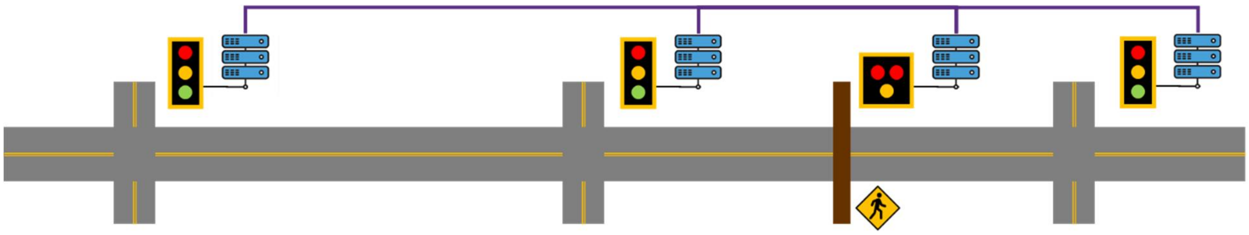


Figure 44 – Traffic Signal Coordination

As shown below, a total of 15 traffic volume combinations were modeled:

		5 pedestrians/hour
75% of existing PM peak vehicular volume		*50 pedestrians/hour*
100% of existing PM peak vehicular volume	×	*100 pedestrians/hour*
125% of existing PM peak vehicular volume		*200 pedestrians/hour*
		500 pedestrians/hour

This brought the total number of modeled scenarios to 180:

2 corridors × 6 ped crossing traffic control combinations × 15 traffic volume combinations = 180 scenarios

9.2.2. Modeling Methodology

Vissim models were developed to represent the existing roadway geometrics and motorized traffic volumes for the two corridors. These were combined with hypothetical pedestrian volume cases representing various levels of time-space conflict between vehicles and pedestrians. Motor vehicle volume targets were set based on the field traffic counts for the PM peak hour. These volumes were encoded using the Vissim turning movement flows feature, avoiding the need for origin-destination matrix estimation. As noted earlier, RRFBs were modeled using the Vissim "priority rules" feature and PHBs were modeled as mid-block signals with timing plans designed to mimic PHB operations.

Both corridors were coded as 35 mph zones, with actual traffic speeds typically about 7 mph faster than the speed limit. Pedestrian facilities at signalized intersections were coded using Vissim's implementation of the Weideman model, while the mid-block pedestrian crossings were coded using the Vissim Social Force model for enhanced realism.

To account for some of the real-world variations in human behavior, Vissim incorporates many stochastic variables. For example, preferred driving speed varies from one driver to another, and preferred walking speed varies from one pedestrian to another. Within the Vissim software architecture, “seed” values are used to initialize random number sequences. For this project, each combination of traffic control, motorized traffic volume, and pedestrian volume was analyzed using at least 3 random seeds and the results were averaged to prepare summary statistics and the graphics shown in subsequent figures. Consistent with Vissim’s stochastic traffic assignment algorithm, the traffic volumes generated by the model varied slightly depending on the seed number.

9.2.3. Signal Timing Optimization

Existing signal timing plans for the two corridors were obtained from the Regional Transportation Commission (RTC) of Southern Nevada. For the initial set of model runs, the existing timings were encoded for the PM peak hour in the corresponding models. All existing intersection signals operate on a 140 second cycle length. For the coordinated signal models, the pedestrian crossings were modeled as half-cycle signals, i.e., a cycle length of 70 seconds.

The signals were initially encoded using the Econolite ACS/3 emulator for Vissim, which provides access to many of the advanced features of modern traffic signal controllers. Later it was determined that Nevada DOT did not own this module. The signals were then re-coded using Vissim's native RBC (ring barrier controller), which emulates most commonly available features of typical North American signal controllers. Since the timing plans used in the Las Vegas area are fairly standard, no loss of fidelity is anticipated.

After reviewing the results of the initial model runs, Nevada DOT determined that the existing field timings are unlikely to be optimal for the traffic using the modeled portions of the MLK and Bonanza corridors. To obtain an improved baseline condition, the timing plans were re-evaluated. Synchro 11 (Cubic Transportation Systems 2023) was used to develop the timing plans for each of the evaluation scenarios.

Base timings for each intersection were input into the Synchro model. These values included minimum green, yellow, all red, and pedestrian clearance times. The cycle lengths at all the signalized intersections were set to run a 140 second cycle to allow for coordination along the corridors. The only exception to the 140 second cycle length was at the pedestrian hybrid beacons; as in the preliminary model runs these were set to run a half-cycle (70 seconds), which still allows for coordination, but minimizes the time a pedestrian would need to wait to be served at the crossing. After selecting the cycle length, maximum phase splits were also selected with the goal to minimize the delay at each intersection. The corridor models were additionally reoptimized for three volume scenarios, including the original volume scenario with 100% of the corridor through-traffic volumes, and two alternatives with corridor through-traffic volumes adjusted to 75% and 125% of the base value.

To coordinate the traffic signals along each of the study corridors, offsets were selected for each of the evaluation scenarios for each volume set individually. Offsets were selected using Synchro's time-space diagram tool by examining the vehicle flows set at a the 90^{th} percentile flow level. Time-space diagrams for the modeled corridors are provided in **Appendix E**. Generally speaking, the direction of travel with the highest volume was initially prioritized to maximize the throughput along each corridor. Then the other direction of travel was examined to identify areas where the offset could be changed to allow for better flow in the other direction without significantly affecting the prioritized direction of travel.

9.2.4. RRFB Modeling

The typical approach to traffic signal control modeling in Vissim does not replicate the performance of rectangular rapid flashing beacons (RRFBs). Instead, the team modeled the RRFB scenarios as conflict points where one traffic stream (vehicles) must yield to another (pedestrians). For both corridors the models were coded such that vehicles will yield to pedestrians approaching from the left for the entire time the pedestrian occupies the crosswalk, and vehicles yield to pedestrians approaching from the right until the pedestrian reaches the median. The sponsor's representative stated that this combination of behaviors is typical for the study area.

Using this RRFB modeling method, the model results are sensitive to the *effective* width of the crossing. This is the distance from the point at the upstream end of a pedestrian trip where vehicles become aware of the conflicting pedestrian, to the downstream point where the pedestrian is no longer deemed to be in conflict with the motor vehicle's path. To establish this effective width, all pedestrians were assumed to be visible to vehicles when they reached points about 5 feet upstream of the back-of-curb. For the Bonanza Road and 22nd Street site, this assumption implies implementing new parking restrictions near the crosswalk.

9.2.5. PHB Modeling

As noted earlier, the PHBs were modeled as mid-block signals with timing plans representative of PHB operations. The main difference is that the PHB's flashing red phase could not be modeled explicitly with the Vissim RBC signal controller. This was addressed through the pedestrian clearance interval settings. As shown in **Table 20**, walk phase duration and clearance intervals were set to be consistent with those currently used at the adjoining signalized intersections. Vissim requires a pedestrian walking speed distribution. Values for pedestrian walking speed were taken from results of a previous field study by Gates et al. (2006).

Table 20 – Pedestrian signal timing parameters

Parameter	N. Martin Luther King Boulevard	E. Bonanza Road
Walk Phase	5 seconds	7 seconds
Clearance Time: One-Stage Crossing	28 seconds	21 seconds
Clearance Time: Two-Stage Crossing	14 seconds	11 seconds

9.2.6. Modeling Results

The results of the simulation are shown in **Figure 45** and **Figure 46** respectively for the MLK and Bonanza corridors. Detailed numerical results are presented in **Table 21** and **Table 22**. In each subfigure, the chart on the left shows the delay to vehicular through traffic while the chart on the right shows the delay encountered by pedestrians at the pedestrian crossing. Results are shown as pedestrian volumes were increased from a minimum of 5 peds/hr to 500 peds/hr, for the six control scenarios described earlier. Altogether these charts contain results for 180 simulation scenarios.

9.2.6.1. RRFB Simulation Results

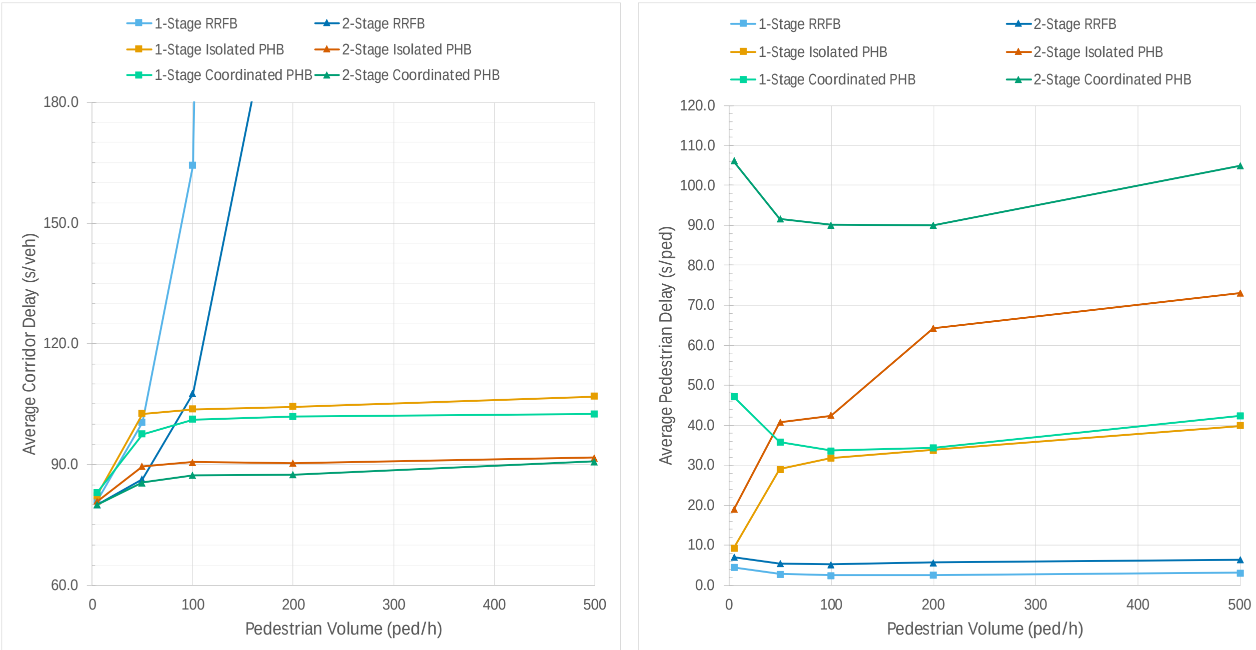
Overall results were similar for both corridors (with a few differences) and did not substantially change with variations to the corridor through traffic. The delay to vehicular traffic increased substantially with pedestrian volume for the 1-stage and 2-stage RRFB treatments, although in general the 2-stage RRFB had lower vehicular delay. At around 100 peds/hr for the 1-stage and 200 peds/hr for the 2-stage RRFB, there were almost always pedestrians crossing the street. At the highest volume levels the street was effectively shut down for vehicular traffic, with newly arriving pedestrians starting to cross before previous pedestrians completed their crossings. In short, the modeling shows that under high pedestrian demand the RRFB resulted in intolerable delays for motorists and long vehicular queues that could potentially gridlock the corridor. Conversely, pedestrian delays were lowest for the RRFB treatments, with the 1-stage RRFB having slightly lower delay than the 2-stage RRFB.

9.2.6.2. PHB Simulation Results

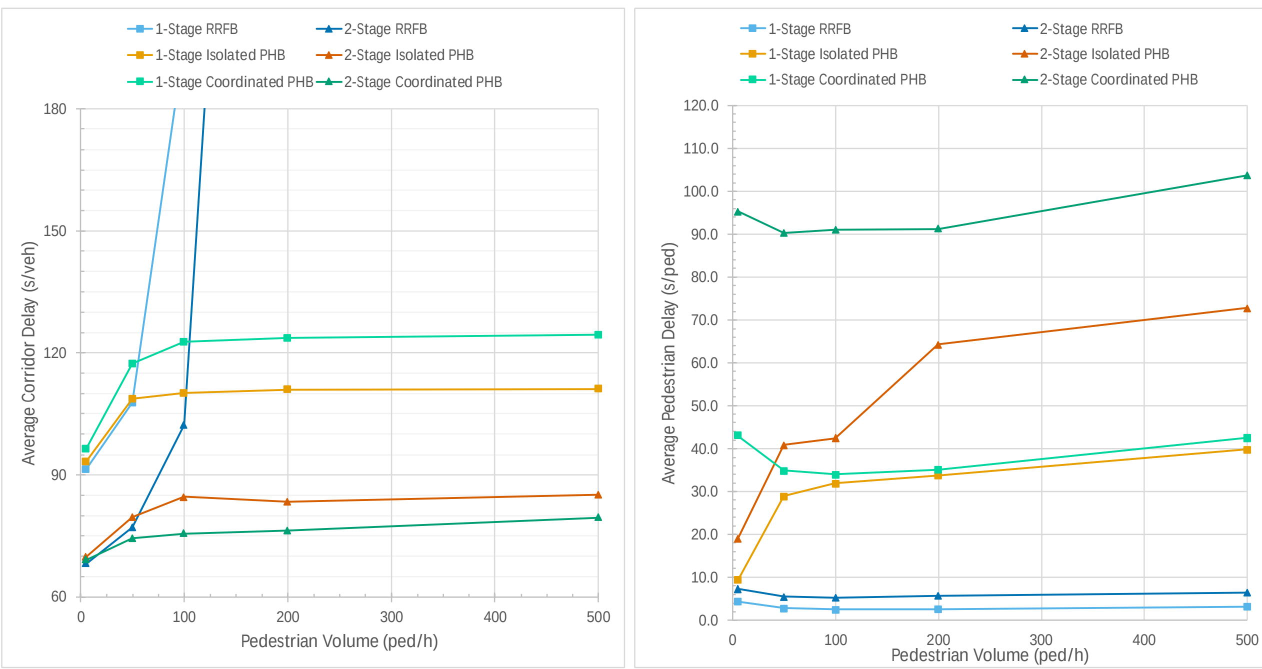
As with the RRFB simulations, the overall results of the PHB simulations were similar for both corridors (with a few differences) and did not substantially change with variations to the motor vehicle traffic. The PHB efficiently handled much higher levels of pedestrian demand. The vehicular delay for the PHB treatments seemed to level off at around 50 peds/hr for the other treatments, largely because of the 30-second minimum time used to serve the vehicular movement. At pedestrian volumes around 50 peds/hr and above, there was a near constant call for the pedestrian crossing, meaning that the crossing effectively served as a meter for the corridor traffic.

The vehicular delay was usually lower for coordinated control than for isolated control, although in the case of MLK, the 1-stage PHB did not show a benefit from coordination, although this was true for the 2-stage PHB. For the Bonanza corridor, coordination consistently led to a reduction in vehicular delay for the 1-stage crossing but seemed not to affect the performance of the 2-stage crossing. At MLK, the 2-stage PHB treatments had lower delay than the 1-stage PHB treatments, but the opposite was true for Bonanza. This is likely due to the different intersection spacing and traffic volumes present on the two corridors, with MLK having higher volumes.

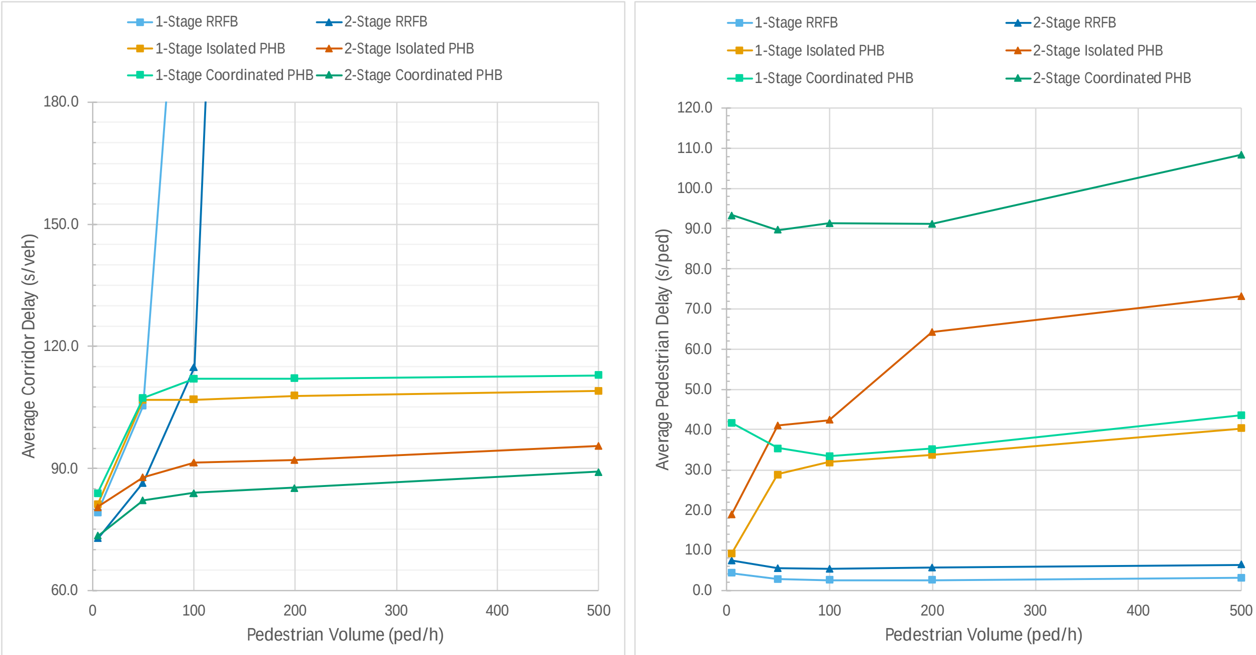
With respect to the pedestrian delay, the PHB treatments all had higher pedestrian delay than the RRFB treatments. Pedestrian delay tended to level off somewhere between 100 and 200 peds/hr, varying by scenario. For both corridors, the 2-stage crossings had higher delay than 1-stage crossings. There was a tendency for pedestrians to have to wait in the median refuge area and wait to receive a WALK indication for the second stage. Coordination only marginally affected pedestrian delay for the 1-stage crossing, but substantially increased the pedestrian delay for the 2-stage crossing. Thus, among the PHB treatments, pedestrian delay was lowest for the 1-stage crossing (with a slight increase for coordination) and it was highest for the 2-stage crossing under coordination.



(a) 75% Volume

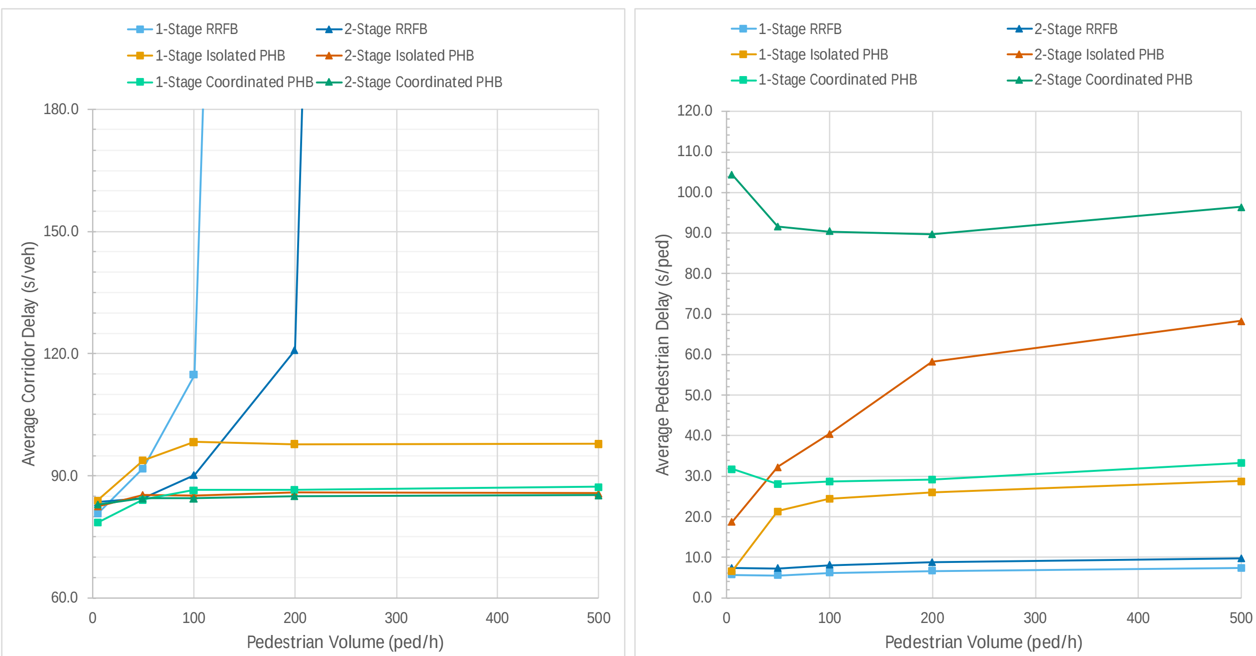


(b) 100% Volume

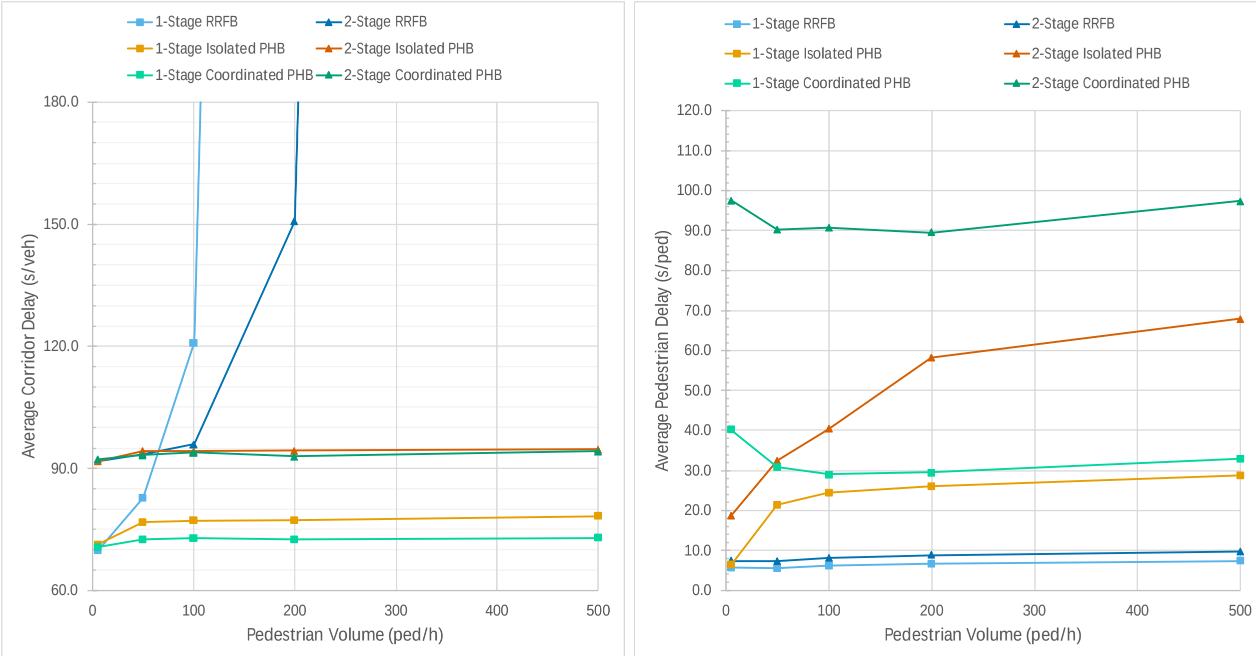


(c) 125% Volume

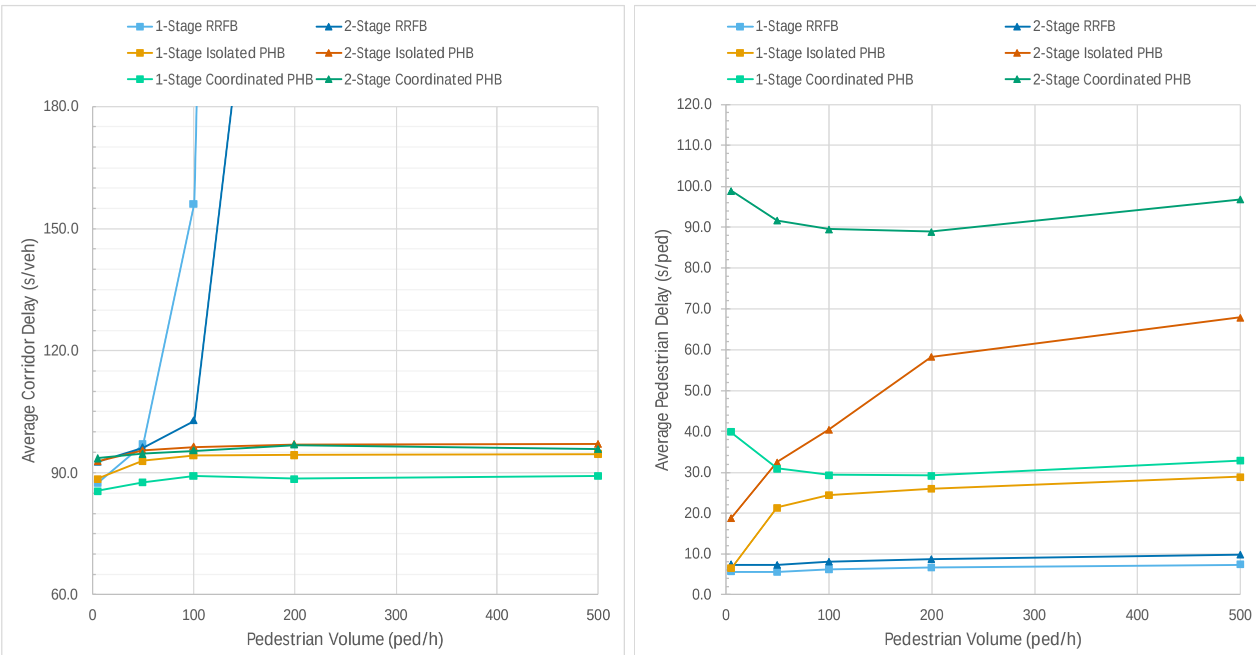
Figure 45 – Results of VISSIM Modeling
(Corridor Vehicular Delay and Pedestrian Delay at the Pedestrian Crossing)
for the Martin Luther King Boulevard Corridor



(a) 75% Volume



(b) 100% Volume



(c) 125% Volume

Figure 46 – Results of VISSIM Modeling (Corridor Vehicular Delay and Pedestrian Delay at the Pedestrian Crossing) for the Bonanza Road Corridor

Table 21 – Detailed Results for the Martin Luther King Boulevard Corridor

(a) 75% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	81.0	100.5	164.4	∞	∞
2-Stage RRFB	80.0	86.4	107.6	231.9	∞
1-Stage Isolated PHB	82.3	102.6	103.8	104.4	106.9
2-Stage Isolated PHB	80.8	89.5	90.6	90.3	91.7
1-Stage Coordinated PHB	83.1	97.6	101.2	101.9	102.6
2-Stage Coordinated PHB	80.0	85.5	87.3	87.5	90.8

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	4.5	2.8	2.5	2.6	3.1
2-Stage RRFB	7.1	5.4	5.2	5.6	6.4
1-Stage Isolated PHB	9.3	29.0	31.8	33.8	39.9
2-Stage Isolated PHB	18.9	40.8	42.5	64.2	73.1
1-Stage Coordinated PHB	47.2	35.8	33.6	34.4	42.4
2-Stage Coordinated PHB	106.1	91.6	90.1	90.0	104.9

(b) 100% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	91.5	107.8	196.1	∞	∞
2-Stage RRFB	68.2	77.2	102.3	∞	∞
1-Stage Isolated PHB	93.3	108.8	110.1	111.0	111.2
2-Stage Isolated PHB	69.9	79.7	84.6	83.3	85.1
1-Stage Coordinated PHB	96.5	117.4	122.7	123.6	124.5
2-Stage Coordinated PHB	69.2	74.4	75.6	76.3	79.6

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	4.3	2.8	2.5	2.6	3.1
2-Stage RRFB	7.3	5.4	5.3	5.7	6.4
1-Stage Isolated PHB	9.3	28.8	31.9	33.7	39.8
2-Stage Isolated PHB	18.9	40.8	42.4	64.3	72.8
1-Stage Coordinated PHB	43.0	34.9	34.0	35.1	42.5
2-Stage Coordinated PHB	95.3	90.3	91.1	91.3	103.8

(c) 125% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	79.2	105.4	272.6	∞	∞
2-Stage RRFB	72.8	86.5	114.9	∞	∞
1-Stage Isolated PHB	81.2	106.8	106.9	107.9	109.1
2-Stage Isolated PHB	80.5	87.8	91.4	92.1	95.6
1-Stage Coordinated PHB	83.9	107.3	112.0	112.2	112.9
2-Stage Coordinated PHB	73.4	82.1	83.9	85.2	89.1

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	4.3	2.8	2.5	2.6	3.1
2-Stage RRFB	7.4	5.5	5.4	5.7	6.4
1-Stage Isolated PHB	9.2	28.9	31.9	33.7	40.3
2-Stage Isolated PHB	18.9	41.0	42.4	64.3	73.3
1-Stage Coordinated PHB	41.7	35.4	33.4	35.2	43.6
2-Stage Coordinated PHB	93.3	89.7	91.4	91.2	108.4

Table 22 – Detailed Results for the Bonanza Road Corridor

(a) 75% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	80.7	91.8	114.8	∞	∞
2-Stage RRFB	83.5	84.5	90.2	120.8	∞
1-Stage Isolated PHB	84.0	93.8	98.3	97.7	97.8
2-Stage Isolated PHB	82.4	85.3	85.1	85.9	85.7
1-Stage Coordinated PHB	78.5	84.1	86.5	86.6	87.3
2-Stage Coordinated PHB	82.9	84.4	84.4	85.0	85.2

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	5.7	5.6	6.2	6.7	7.4
2-Stage RRFB	7.4	7.3	8.1	8.8	9.8
1-Stage Isolated PHB	6.5	21.4	24.4	26.0	28.8
2-Stage Isolated PHB	18.8	32.3	40.4	58.2	68.3
1-Stage Coordinated PHB	31.8	28.1	28.7	29.2	33.3
2-Stage Coordinated PHB	104.4	91.6	90.4	89.7	96.3

(b) 100% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	69.8	82.7	120.9	∞	∞
2-Stage RRFB	91.7	93.5	96.0	150.7	∞
1-Stage Isolated PHB	71.3	76.8	77.2	77.3	78.3
2-Stage Isolated PHB	91.8	94.3	94.2	94.4	94.7
1-Stage Coordinated PHB	70.7	72.5	72.8	72.5	73.0
2-Stage Coordinated PHB	92.2	93.3	93.9	93.0	94.2

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	5.7	5.6	6.2	6.7	7.4
2-Stage RRFB	7.4	7.3	8.1	8.8	9.8
1-Stage Isolated PHB	6.5	21.4	24.4	26.0	28.8
2-Stage Isolated PHB	18.8	32.5	40.4	58.2	67.9
1-Stage Coordinated PHB	40.2	30.9	29.0	29.5	33.0
2-Stage Coordinated PHB	97.5	90.2	90.8	89.6	97.3

(c) 125% volume.

Average Vehicular Delay (seconds/vehicle)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	87.5	96.9	156.2	∞	∞
2-Stage RRFB	92.7	96.2	102.8	∞	∞
1-Stage Isolated PHB	88.5	92.9	94.3	94.4	94.6
2-Stage Isolated PHB	92.9	95.5	96.3	97.0	97.0
1-Stage Coordinated PHB	85.5	87.6	89.2	88.5	89.2
2-Stage Coordinated PHB	93.6	94.7	95.4	96.8	95.8

Average Pedestrian Delay (seconds/pedestrian)					
Pedestrian Volume (ped/h)	5	50	100	200	500
1-Stage RRFB	5.7	5.6	6.2	6.7	7.4
2-Stage RRFB	7.4	7.3	8.1	8.8	9.8
1-Stage Isolated PHB	6.5	21.4	24.4	26.0	28.9
2-Stage Isolated PHB	18.8	32.5	40.4	58.3	67.9
1-Stage Coordinated PHB	39.8	30.9	29.4	29.2	32.9
2-Stage Coordinated PHB	98.9	91.6	89.4	88.8	96.8

9.3. Modeling Conclusions

Although the Vissim model runs do not cover all possible combinations of mid-block crossing design and road user demand that occur in Nevada, some conclusions can be drawn based on the analysis. For clarity, these are described below from the separate perspectives of vehicular and pedestrian road users.

9.3.1. Vehicular Perspective

- Vehicular delays at RRFBs became excessive when the pedestrian volume exceeded approximately 75 to 100 ped/h. The threshold depends on the conflicting vehicular traffic volume and the width of the pedestrian crossing. The breakdown threshold is higher if a two-stage crossing is used at the RRFB. The results were sensitive to modeling assumptions such as driver yielding behavior and pedestrian walking speed, and are thus subject to future refinement based on empirical field studies.
- Two-stage pedestrian crossings generally reduce vehicular delays compared to single-stage crossings, and this is likely to be the case for all four types of signalized mid-block crossings (RRFBs, enhanced amber beacons, PHBs, and mid-block signals). These benefits are greatest under high vehicular and pedestrian volumes.
- The benefit to drivers derives from two sources. First, a two-stage crossing will almost always reduce the stopping time for motor vehicles, since they only have to wait for the pedestrians to cross half the roadway. Second, in corridors with coordinated signals the use of two-stage crossings makes it easier to obtain efficient two-way traffic progression, especially if a mid-block crossing is asymmetrically spaced between the upstream and downstream signals. In somewhat more technical terms, the use of a two-stage crossing supports corridor coordination by allowing different cycle offsets to be selected for each travel direction.
- Under the optimized signal timings, the benefits of coordinating of the PHB with the corridor signal timing plan were relatively small for the scenarios modeled in this study. The benefits of coordination appear to be somewhat greater when the timing plan is sub-optimal, but this line of investigation was not pursued in depth in the present study.
- Per unit of expenditure, implementing isolated PHBs (or mid-block signals) is likely to yield greater overall benefit to road users than implementing coordinated PHBs (or coordinated mid-block signals). If a single PHB (or mid-block signal) is being added to an existing coordinated corridor, the cost-effectiveness of coordinating it will vary with the interconnection technology and communications infrastructure available at the site. Conversely, if coordination is being added along an entire corridor, it will generally be advantageous to include mid-block pedestrian crossings as part of the coordinated system.

9.3.2. Pedestrian Perspective

- RRFBs result in the lowest modeled pedestrian delay based on assumed immediate driver compliance with the signal. This modeling assumption may not hold under high motor vehicle volume scenarios. That is to say, previous field research suggests that driver compliance with RRFBs declines as traffic volume increases, potentially undermining some of the pedestrian safety benefits of the device.
- In terms of delay, single-stage isolated PHBs are the second-best option for pedestrians. They are preferable to RRFBs in terms of driver compliance and pedestrian safety.
- Under the optimized signal timings, isolated two-stage PHBs result in a modest increase in pedestrian delay for pedestrian volumes less than about 100 ped/h. These delays increase sharply at volumes over 200 ped/h.
- In general, coordinated two-stage PHBs result in substantial pedestrian delays (typically two waiting periods of 45-60 seconds each).

9.4. Timing Recommendations

9.4.1. Rectangular Rapid Flashing Beacons

The MUTCD offers the following guidance on the duration of the flashing interval (Section 4L.03 paragraph 03): “The minimum duration of a predetermined period of operation of the RRFBs following each actuation should be based on the procedures for the timing of pedestrian clearance times for pedestrian signals.” Further support is offered in the next paragraph (Section 4L.03 paragraph 04): “One consideration for lengthening the duration of the predetermined period of operation of the RRFBs is adding the perception/reaction time for pedestrians to confirm that a vehicle will yield or stop.”

From MUTCD Section 4I.06, paragraph 06, regarding the duration of pedestrian clearance time: “…the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or edge of pavement at the end of the [Walk] signal indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.”

From these statements, the duration of the RRFB flashing interval is:

(RRFB Flashing Interval Duration) = (Perception/Reaction Time) + (Pedestrian Clearance Time)

Here, the “Perception/Reaction Time” is the duration of time referenced in the MUTCD “for pedestrians to confirm that a vehicle will yield or stop”, and the pedestrian clearance time is defined in MUTCD Section 4I.06 paragraph 06:

(Pedestrian Clearance Time) = (Crossing Width, ft) / 3.5 ft/s

The MUTCD does not provide a duration for the “perception/reaction time”. The North Carolina DOT has published a guideline for RRFB timing adds a value of 7 seconds to the pedestrian clearance time. The following expression estimates the amount of time needed for a driver to react to the RRFB and bring the vehicle to a stop can be used, as an upper bound for the “perception/reaction time” needed for a pedestrian to confirm that a vehicle will yield or stop:

(Perception/Reaction Time) = $t + 1.47 \times V / a$

Here, t is the “brake reaction time” (s) as defined in the AASHTO “Green Book” (Policy on Geometric Design of Highways and Streets, 7th edition) for stopping sight distance, V is the vehicle speed (mph), and a is the rate of deceleration (ft/s2). The factor 1.47 converts the speed value from mph to ft/s. For stopping sight distance calculations, the Green Book uses t = 2.5 s and a = 11.2 ft/s2. Engineering judgment should be exercised when selecting a value for V, given that speed limits may not affect typical vehicle speeds on the approach to the RRFB.

For a 50-ft wide street (56-ft crossing distance) with 45 mph vehicle speed and level grade, the total flashing interval is:

(2.5 s) + (1.47 × 45 mph) / (11.5 ft/s2) + (56 ft) / (3.5 ft/s) = 24.3 s (round up to 25 s).

9.4.2. Enhanced Amber Beacons

The MUTCD provides guidance on warning beacons in section 4S.03. This guidance does not include a recommendation about the duration of a flashing yellow interval for warning beacons used to enhance a pedestrian crossing. In lieu of more specific guidance for EABs, the MUTCD guidance on the duration of the flashing interval for RRFBs can be applied to the flashing interval for EABs.

For a 50-ft wide street (56-ft crossing distance) with 45 mph vehicle speed and level grade, the total flashing interval is:

(2.5 s) + (1.47 × 45 mph) / (11.5 ft/s2) + (56 ft) / (3.5 ft/s) = 24.3 s (round up to 25 s).

9.4.3. Pedestrian Signals

Pedestrian signals include PHBs, which use a specific display sequence with multiple intervals that must be configured, and midblock pedestrian signals, which are configured similar to traffic control signals at "regular" intersections.

9.4.3.1. Pedestrian Hybrid Beacon Timing

MUTCD section 4J.03 covers PHB operation and includes the definition of the PHB display sequences for vehicles and for pedestrians. The vehicle sequence is: (1) flashing circular yellow signal indication, (2) steady circular yellow signal indication, (3) steady circular red indication during the WALK interval, (4) alternating flashing circular red signal indications during the pedestrian change interval, and (5) dark. The pedestrian sequence is: (1) steady Don't Walk during the flashing yellow and steady yellow circular indications; (2) Walk during the display of the steady red circular indication; (3) Flashing Don't Walk during the display of the alternating flashing circular red indication. Figure 47 explains the display of these intervals.

The MUTCD includes the following statements about the duration of these intervals: "The duration of the flashing yellow interval should be determined by engineering judgment." (MUTCD Section 4J.03, paragraph 05) and "The duration of the flashing yellow interval should not vary on a cycle-by-cycle basis." (MUTCD Section 4J.03, paragraph 06).

The flashing circular yellow interval follows a period where the vehicular display is dark. The MUTCD does not provide guidance on the duration of this interval. Publication FHWA-HRT-16-040 (Evaluation of Pedestrian Hybrid Beacons and Rapid Flashing Beacons) includes example PHB timing with 3–4 s used for this interval. This interval should be sufficient to call driver attention to the presence of the PHB in advance of the display of steady circular yellow. A longer duration should be considered in areas where drivers are unfamiliar with PHBs.

The duration of the steady circular yellow should be set according to agency policy for yellow change intervals for traffic control signals. During the flashing and steady circular yellow intervals, the pedestrian signal should display a steady Don't Walk indication.

The steady red circular indication should be displayed for the same amount of time as the pedestrian Walk indication. The MUTCD criteria for minimum Walk timing should be applied to this interval. The MUTCD states that the minimum Walk interval is 7 seconds, but notes in MUTCD 4I.06 paragraph 12 that "if pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used."

The alternating flashing circular red indication should be displayed for the same amount of time as the pedestrian clearance time. For traffic control signals, the MUTCD specifies that the sum of the Flashing Don't Walk and Steady Don't Walk buffer intervals should exceed the pedestrian clearance time. The MUTCD does not state a requirement for a the Steady Don't Walk interval duration are specified for PHBs. Consequently, the flashing Don't Walk should be as long as the entire pedestrian clearance time.

For a 50-ft wide street (56-ft crossing distance) with 45 mph vehicle speed and level grade, the intervals are:

- During Pedestrian Steady "Don't Walk":

    - Vehicular Flashing Circular Yellow: Use at least 4 s.
    - Vehicular Steady Circular Yellow: Set according to agency policy for yellow change interval timing. For example, if agency policy refers to the Signal Timing Manual recommendations, for approach speeds of 45 mph the yellow interval should be set to at least 4.3 s (from Exhibit 6.2 in the Signal Timing Manual).
- During Pedestrian “Walk”:
    - Vehicular Steady Circular Red: Set equal to the display of Walk. The MUTCD indicates that the minimum Walk interval is 7 s, but values as low as 4 s may be used.
- During Pedestrian “Flashing Don’t Walk”:
    - Vehicular Alternating Flashing Circular Red: Set equal to the pedestrian clearance time. For a 50-ft wide street (56-ft crossing distance), the pedestrian clearance interval is (56 ft) / (3.5 ft/s) = 16 s.

9.4.3.2. Midblock Pedestrian Signal Timing

For midblock pedestrian signal timing, the requirements outlined in MUTCD section 4I.06 for “regular” traffic control signals should be used:

- The MUTCD states that the minimum Walk interval is 7 seconds, but notes in MUTCD 4I.06 paragraph 12 that “if pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used.”
- The pedestrian clearance time is calculated as explained previously, using a walking speed of 3.5 ft/s. The total duration of the Flashing Don’t Walk interval and the Steady Don’t Walk buffer interval (between the end of Flashing Don’t Walk and the start of the next conflicting movement green) should be greater than the pedestrian clearance time. The MUTCD requires that the Steady Don’t Walk buffer interval be at least 2 seconds in duration.
- The duration of yellow change and red clearance interval duration should be set according to agency policies for traffic control signals.

9.4.3.3. Single vs Two-Stage Crossing

Although some roadways lack sufficient width for a median refuge, where geometrically feasible the use of two-stage mid-block pedestrian crossings is recommended for the high-volume arterials typical of larger Nevada cities. The two-stage design (with median refuge) is advantageous for pedestrian safety and makes it easier to maintain two-way corridor traffic progression because you can stop one direction of vehicular travel at a time on the arterial and the amount of time vehicular traffic is stopped is substantially shorter compared to the single stage crossing.

As noted earlier, the use of a fenced, offset median refuge (**Figure 18**) has several advantages, including reduced potential for pedestrians to dart across the street in a misjudged small gap. In addition, by offsetting the crossing to the right, pedestrians face oncoming traffic while completing the zig-zag, increasing their awareness of the location and speed of approaching vehicles. Compared to non-offset median refuges, the larger size of the offset design increases visibility to motorists, and the vertical elements of the fencing further enhance conspicuity.

In heavy traffic, the Vissim modeling results indicated that the use of a two-stage crossing will usually increase pedestrian delay compared to a single-stage design. Conversely, the use of a two-stage design generally reduces motorist delays for both isolated and coordinated signals. This is primarily because the red interval for motorists is substantially shorter: the signals can be timed to allow motorists to proceed after the pedestrians reach the middle of the roadway, instead of waiting for pedestrians to cross the entire width.

The signal progression advantages of a two-stage crossing are particularly important when the traffic volume is high and the mid-block crossing is asymmetrically spaced between the upstream and downstream signals.

9.4.3.4. Isolated vs Coordinated

Under the optimized signal timings developed for the present study, the benefits of coordinating of the PHB with the corridor signal timing plan were modest. The benefits of coordination appear to be somewhat greater when the timing plan is sub-optimal, but this line of investigation was not pursued in depth in this study.

9.4.3.5. PHB Timing Parameters

Figure 47 illustrates the basic phasing diagram for a pedestrian hybrid beacon. The following timing parameters were adopted for the present study:

- Isolated PHBs:
  - 30 second minimum "green" (dark signal) time for vehicles
  - 5 second walk time
  - Pedestrian clearance time proportionate to the distance to be crossed (3.5 ft/s walking speed per the MUTCD)
- Coordinated PHBs:
  - Both of the analyzed corridors were in zones with 140 second cycle length. The PHBs were configured to run on a 70-second cycle to provide two pedestrian crossing opportunities per corridor cycle
  - 5 second minimum walk time
  - Pedestrian clearance time proportionate to the distance to be crossed (3.5 ft/s walking speed per the MUTCD)
  - Offsets adjusted to optimize corridor progression (PHB dark for green wave)

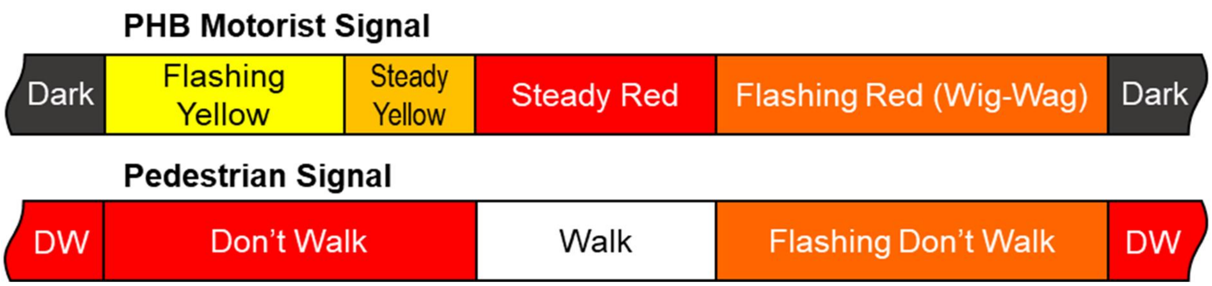


Figure 47 – PHB Phasing Diagram

10. CONCLUSIONS AND RECOMMENDATIONS

10.1. Pedestrian Treatment Selection Overview

Pedestrian safety has been a major concern throughout the 140-year history of the automobile. Over the decades, numerous mid-block pedestrian safety treatments have been developed including RRFBs, EABs, PHBs, and three-color mid-block traffic signals (see illustrations in **Section 1**). In low-speed environments, any of these devices can be enhanced with a raised crosswalk that functions as a speed table. Similarly, wherever the available road space is sufficiently wide, any of the treatments can be enhanced with a median refuge to provide a two-stage crossing, which will benefit both pedestrian safety and the efficient flow of motorized traffic.

Grade separation is mandatory when pedestrians must cross a freeway or other very high speed, very high volume facility. A common example in the Western US is passenger access to transit stations located in the freeway median. In spite of their considerable capital costs, grade separations can also be desirable in locations with high pedestrian volumes--not only to prevent pedestrian crashes but also to reduce motorist delays. The set of four pedestrian overpasses at S Las Vegas Blvd and E Flamingo Road in Las Vegas is an example of a location where grade-separated crossings benefit all road users. In some cases, grade separations can be fully integrated with the architecture of adjacent buildings to provide seamless connections at the second- or third-floor level.

Many pedestrian crossings in the United States are currently undertreated, while some are overtreated. This can potentially be attributed to the lack of a treatment hierarchy in national guidance documents. In addition, the literature review conducted for this project revealed great inconsistency in the methods agencies have used to select pedestrian crossing treatments in the past. Some agencies have relied on very rigid numerical criteria (typically combinations of pedestrian and vehicular volume) while others recommended considering a wide range of hard-to-quantify factors such as land use, pedestrian age and ability, and even the economic development goals for the area near the crossing.

In a balanced approach, objective criteria can be used to identify minimum treatment thresholds. With these minimums in mind, a higher level of treatment (or treatment enhancements such as a raised crosswalk or median refuge) can be applied at sites with complications such as limited visibility, extreme peaking of pedestrian demand, or frequent use by elderly or intoxicated pedestrians.

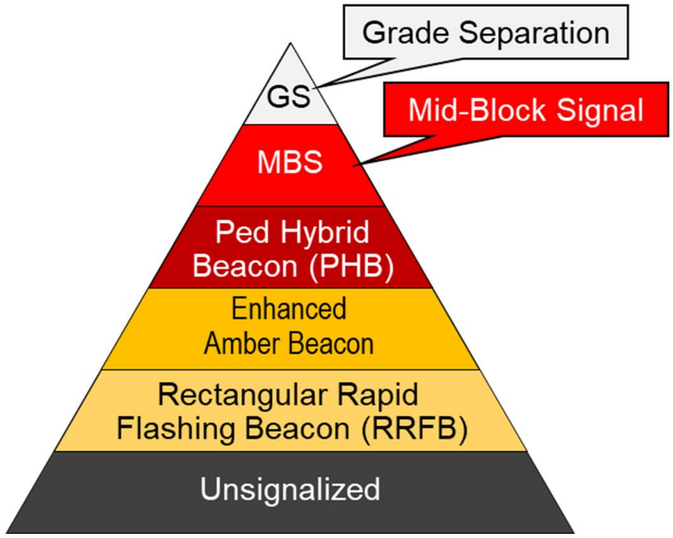


Figure 48 – Recommended Pedestrian Crossing Treatment Hierarchy

Toward this end, the project team developed a recommended treatment hierarchy (**Figure 48**) and a Nevada Pedestrian Treatment Evaluation Workbook that takes four readily measurable factors into consideration (traffic speed, roadway configuration, motorized traffic volume, and pedestrian traffic volume). Using this information, the worksheet generates star ratings for six potential treatments. In addition, the workbook performs an economic analysis based on the pedestrian safety benefits of the treatment and default or user-supplied costing data.

A few hard-and-fast rules are built into the workbook. For example, the workbook returns a zero-star rating for RRFB applications on high speed (40+ mph) roadways, indicating this not a recommended application of the RRFB. Similarly, only a grade separation is considered acceptable when crossing a freeway. The first rule reflects the results of studies identified through the literature review, which indicate that motorist compliance with RRFBs deteriorates markedly in high-speed environments. Simply stated, when the traffic is moving quickly, it needs to be brought to a stop before pedestrians are allowed to cross. From this perspective, "red" devices that mandate a stop (PHBs and mid-block signals) can be clearly separated from "yellow" devices that simply warn of possible pedestrian presence (RRFBs and EABs).

A number of field conditions potentially justify the use of a higher-level treatment. For example, the use of a "red" device is strongly recommended for sites where motorists cannot readily see the approaching pedestrians, such as may be the case when a pedestrian path or bike trail crosses a roadway on a skew. Other examples of conditions which could necessitate the use of a higher treatment level include, but are not limited to, extreme peaking of pedestrian demand and frequent use by highly vulnerable pedestrians such as children, elderly people, people with disabilities, and intoxicated people (i.e., proximity to establishments that serve alcohol or other intoxicants).

10.2. Pedestrian Crossings Near Intersections

The traffic signal spacing in major Nevada cities is long compared to most other parts of the United States. For example, one-mile signal spacing is not unusual on Las Vegas area arterials that adjoin populous small-lot single-family residential districts. The relatively long distances between signals increase the likelihood that pedestrians will cross mid-block instead of backtracking to a signalized intersection. There are potentially locations where adding intermediate signal(s) that serve both pedestrians and side-street traffic would be preferable to adding mid-block pedestrian crossings. One potential rule of thumb is to compare the signal spacing with the spacing of bus stops, bearing in mind that at most bus stops, approximately half of passengers must cross the roadway to reach their ultimate destination.

RRFBs, EABs, PHBs, and mid-block signals were all designed for true mid-block crossings--those which do not coincide with a street or major commercial driveway. The MUTCD cautions against the use of PHBs near intersections, stating that a PHB "*should* be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs" (emphasis added). No comparable language is provided for RRFBs in FHWA Interim Approval 21.

When a pedestrian crossing is located at or near a three-leg intersection, the first order of business is to determine whether the site requires a mid-block pedestrian treatment, or is better suited to a regular three-color traffic signal that serves both pedestrians and side-street motorized traffic. At such sites, the MUTCD traffic signal warrants should be reviewed. This is particularly important if a PHB is under consideration, given that the cost of installing and maintaining a PHB differs only marginally from the cost of a traffic signal.

Perhaps because of the MUTCD's admonishment against of the use of PHBs near intersections, the existing research literature contains very little discussion of the use of mid-block pedestrian treatments at four-leg intersections. An important question is whether the side-street traffic will be able to readily determine when the device is illuminated. If vehicles on the side street are unaware that pedestrians have the right-of-way, there is probably an increased risk of a pedestrian being struck by a vehicle turning from the side street.

10.3. Pedestrian Treatment Enhancements

10.3.1. Raised Crosswalks

As noted earlier, the safety of pedestrian crossings on lower-speed (35 mph or less) facilities can be enhanced by providing a raised crosswalk (**Figure 49**). This relatively low-cost treatment functions as a speed table, reducing the likelihood of a vehicle-pedestrian crash and the injury severity if one occurs.

10.3.2. Two-Stage Crossings

Previous research has identified many advantages (and very few disadvantages) for using two-stage pedestrian crossings with an offset, fenced median refuge (**Figure 50**). In general, two-stage crossings are found to:

- Increase pedestrian safety.
- Reduce pedestrian delays when crossing busy roadways.
- Reduce motorist delays since drivers only need to wait for pedestrians to cross half the road.
- Make it possible to optimize the traffic signal timing plan for two-way progression regardless of the spacing between the mid-block crossing and the adjoining signalized intersections.

Photo: Scott Batson/Wikimedia Commons

Figure 49 – An Unsignalized Raised Crosswalk in Portland, Oregon

Photo: Arizona DOT

Figure 50 – Fenced Median Refuge in Arizona, Based on British Design

The British Department for Transport (DfT) has sponsored extensive research on pedestrian crossing safety features. DfT's fenced median refuge design has been optimized for the safety and convenience of all road users, and this design has been adapted for use in Arizona and a handful of Nevada locations. It includes the following features:

- The entry and exit locations of the refuge are offset, and the refuge is fenced, to prevent pedestrians from crossing in a single stage.
- The direction of the offset and the locations of the pedestrian pushbuttons are arranged to force pedestrians to look toward oncoming traffic.

10.3.3. Other Safety Features

Based on safety research, DfT has standardized the use of radar-based on-crossing pedestrian detectors. If a pedestrian has not finished crossing before the end of the pedestrian clearance interval, these detectors trigger an extension of the pedestrian clearance interval. Thus, they provide additional safety for slowly-moving or unpredictable pedestrians such as children, people with severe disabilities, and heavily intoxicated pedestrians. This feature is relatively simple to add to the modern signal controllers typically used in Nevada.

A further refinement sometimes used in British installations is a radar-based detector aimed at the sidewalk approaching the crossing, which cancels the pedestrian call if the pedestrian disappears. In most cases this means the pedestrian has either crossed against the light, or decided not to cross. This feature appears to be used selectively based on past history of false activations. By reducing spurious activations, this feature is said to support driver compliance.

10.4. Simulation Modeling Results

To gain a better understanding of how mid-block pedestrian treatment selection affects vehicular and pedestrian delays, the project team used PTV Vissim 2023 to model a total of 180 combinations of roadway geometrics, pedestrian volume, vehicular volume, mid-block crossing design (single vs two-stage), mid-block crossing type (RRFB vs PHB), and signal operation strategy (isolated vs coordinated). RRFBs were modeled using Vissim "priority rules" and PHBs were modeled as mid-block signals with timing plans designed to closely mimic PHB operations. Although the model runs do not cover all possible combinations that occur in Nevada, some conclusions can be drawn based on the analysis. For clarity, these are described below from the separate perspectives of vehicular and pedestrian road users.

10.4.1. Vehicular Perspective

- Vehicular delays at RRFBs became excessive when the pedestrian volume exceeded approximately 75 to 100 ped/h. The threshold depends on the conflicting vehicular traffic volume and the width of the pedestrian crossing. The breakdown threshold is higher if a two-stage crossing is used at the RRFB. The results were sensitive to modeling assumptions such as driver yielding behavior and pedestrian walking speed, and are thus subject to future refinement based on empirical field studies.
- Two-stage pedestrian crossings generally reduce vehicular delays compared to single-stage crossings, and this is likely to be the case for all four types of signalized mid-block crossings (RRFBs, enhanced amber beacons, PHBs, and mid-block signals). These benefits are greatest under high vehicular and pedestrian volumes.
- The benefit to drivers derives from two sources. First, a two-stage crossing will almost always reduce the stopping time for motor vehicles, since they only have to wait for the pedestrians to cross half the roadway. Second, in corridors with coordinated signals the use of two-stage crossings makes it easier to obtain efficient two-way traffic progression, especially if a mid-block crossing is asymmetrically spaced between the upstream and downstream signals.
- Under the optimized signal timings, the benefits of coordinating of the PHB with the corridor signal timing plan were relatively small for the modeled scenarios. The benefits of coordination appear to be somewhat greater when the timing plan is sub-optimal, but this line of investigation was not pursued in depth in the present study.
- Per unit of expenditure, implementing isolated PHBs is likely to yield greater overall benefit to road users than implementing coordinated PHBs. If a single PHB is being added to an existing coordinated corridor, the cost-effectiveness of coordinating the PHB will vary with the interconnection technology and communications infrastructure available at the site. Conversely, if coordination is being added along an entire corridor, it will generally be advantageous to include mid-block pedestrian crossings as part of the coordinated system.

10.4.2. Pedestrian Perspective

- RRFBs result in the lowest modeled pedestrian delay based on assumed immediate driver compliance with the signal.
- In terms of delay, single-stage isolated PHBs are the second-best option for pedestrians. They are preferable to RRFBs in terms of driver compliance and pedestrian safety.
- Under the optimized signal timings, isolated two-stage PHBs result in a modest increase in pedestrian delay for pedestrian volumes less than about 100 ped/h. These delays increase sharply at volumes over 200 ped/h.
- In general, coordinated two-stage PHBs result in substantial pedestrian delays (typically two waiting periods of 45-60 seconds each).

10.5. Study Limitations

Key limitations of the present study are as follows:

- Due to a lack of empirical field data, it was not possible to validate the Vissim modeling results for the capacity limitations of RRFB devices. Specifically, under high pedestrian volumes the driver behavior at RRFBs is largely unknown.
- Due to limitations of the Vissim software, RRFBs were modeled using "priority rules" that required all vehicles to yield when a pedestrian was present. If a percentage of drivers do

not yield to pedestrians as required by law, average pedestrian delays may be slightly longer and average motorist delays slightly shorter than those indicated by the model results. Since Vissim RBC controller did not allow the flashing red phase to be modeled explicitly, PHBs were modeled as mid-block signals with timings adjusted to mimic PHB operations.

- Although modeling was completed for 180 combinations mid-block crossing device type and site conditions, many more combinations potentially occur within the state of Nevada. In particular the present results may not be fully applicable to core urban areas with short block lengths and intense pedestrian traffic.

10.6. Opportunities for Future Research

Through the present project, the following research needs and opportunities were identified:

- Empirical research should be conducted to identify the safety effects of using various types of mid-block pedestrian treatments in close proximity to intersections and roundabouts.
- PHBs and mid-block signals are very similar from a technical perspective. Future research should be conducted to identify the safety effects of relaxing the warrants for mid-block signals. Is the PHB superior to a mid-block signal, or simply a technical work-around for sites that do not meet the current MUTCD mid-block signal warrants?
- Future research could be conducted to explore opportunities to lower the cost of PHB and mid-block signal installations by making greater use of wireless communication, lower-cost signal controllers, and smaller/lighter mast arms.
- Future research could explore opportunities to improve the safety of PHB installations by adopting on-crossing detection, similar to the British Puffin crossing design.
- Empirical research could be conducted to assess pedestrian and driver acceptance of the less widely used mid-block crossing devices such as enhanced amber beacons.

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APPENDIX A

MID-BLOCK PEDESTRIAN SIGNALIZATION HIERARCHY AND TREATMENT SELECTION

Mid-Block Pedestrian Signalization Hierarchy and Treatment Selection

Introduction

From 2015-2019, Nevada averaged 73.6 pedestrian fatalities per year, a per capita pedestrian death rate 36% above the national average. In addition, according to medical data compiled by the US Centers for Disease Control & Prevention (CDC), each year about 625 Nevada pedestrians required hospitalization after being struck by a motor vehicle, and more than 1500 were treated and released at emergency departments. When all costs are considered, these crashes resulted in losses incurred by insurers, taxpayer-funded healthcare programs, employers, pedestrians, and families totaling well over $1 billion per year. More than a third of vehicle-pedestrian crashes occurred when pedestrians were crossing urban, suburban, or small-town streets at mid-block locations.

Several types of signals and beacons have been shown to improve the safety of mid-block pedestrian crossings. These devices differ in their operational principles: amber beacons warn motorists of pedestrian presence; signals including pedestrian signals manage conflicts between pedestrians and motorized traffic by stipulating which group has the right of way at any specific moment in time; and grade separations (pedestrian overcrossings or undercrossings) physically separate pedestrians from motorized traffic to reduce injury risk. This figure organizes these treatments into a hierarchy based on application environments and cost.

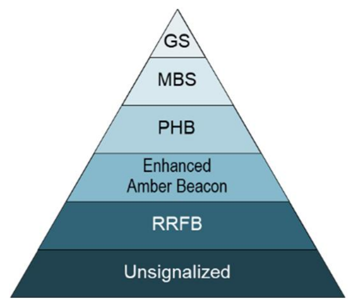

Figure 51. Pedestrian treatment pyramid

Table 32. Hierarchy of pedestrian treatments

6	**Grade Separation (GS)**
5bM	Mid-block signal with median refuge
5b	**Mid-block signal (MBS) – MUTCD Style**
5aM	Mid-block pedestrian signal with median refuge
5a	**Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style**
4M	Pedestrian signal with median refuge
4	**Pedestrian signal**
3XM	Enhanced pedestrian-activated amber beacon with raised crosswalk and median refuge
3M	Enhanced pedestrian-activated amber beacon with median refuge
3X	Enhanced pedestrian-activated amber beacon with raised crosswalk
3	**Enhanced pedestrian-activated amber beacon (EAB)**
2XM	Rectangular rapid-flashing beacon (RRFB) with raised crosswalk and median refuge
2M	Rectangular rapid-flashing beacon (RRFB) with median refuge
2X	Rectangular rapid-flashing beacon (RRFB) with raised crosswalk

2	**Rectangular rapid-flashing beacon (RRFB)**
1XM	Unsignalized marked crossing with raised crosswalk and median refuge
1M	Unsignalized marked crossing with median refuge
1X	Unsignalized marked crossing with raised crosswalk
1	**Unsignalized marked pedestrian crossing (zebra crossing)**
0	No treatment

Table above lists the hierarchy for these treatments, which are described in detail on in a subsequent section of this document. In general, options at the bottom of the hierarchy are suitable for locations with low pedestrian and motor vehicle volumes and low speeds, while higher levels of treatment become necessary with increases in traffic speeds, motor vehicle volumes, or pedestrian volumes.

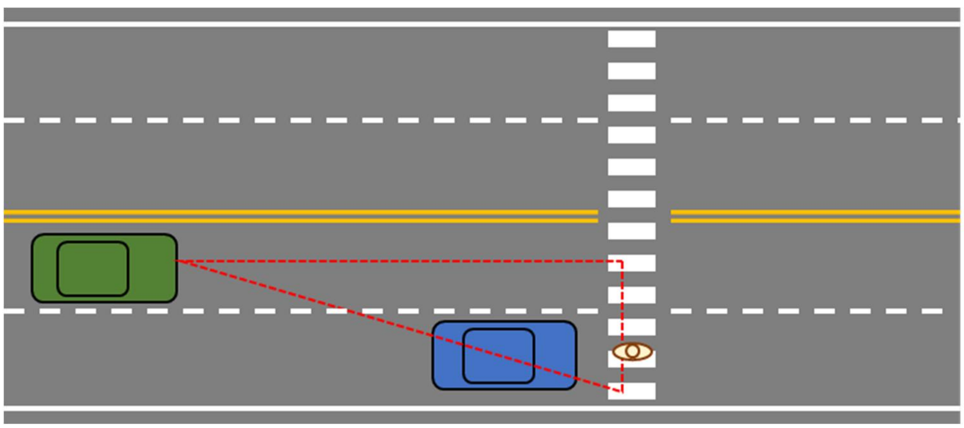

Figure 52. The presence of a stopped vehicle can obstruct pedestrian visibility for vehicles in adjacent lanes

As the shading in the table suggests, an important distinction can be drawn between devices that only warn motorists of pedestrian presence ("yellow" devices), and those which temporally allocate road space by requiring pedestrians and motorists to stop ("red" devices):

- Flashing amber beacons are relatively inexpensive, but rely on the more-or-less voluntary compliance of pedestrians and motorists. As the traffic speed and volume increase, motorist compliance diminishes. Amber beacons are best suited to roadways with only one lane in each direction. When used on multi-lane roadways there is a risk that drivers in some lanes will stop for the pedestrian while drivers in other lanes—possibly unable to see the pedestrian—will not.
- Pedestrian signals and signals tell each group of road users when they must stop and when they may proceed. By reducing ambiguity about who has the right-of-way, both groups of road users can be held legally accountable for violations. In addition, they clearly inform drivers in all lanes that they are required to stop.
- Grade separations usually have the highest up-front cost. If properly designed, they can eliminate up to 100% of conflicts between motorized and non-motorized traffic.

In general:

- Unmarked crossings (treatment type 0) are used on minor residential streets and on two-lane rural highways with very sparse pedestrian traffic.
- Unsignalized marked crossings (treatment types 1, 1X, 1M, and 1XM) are mainly for low-speed roadways with light pedestrian traffic, such as urban minor collectors.
- Amber beacons that provide a *warning* to motorists (treatment types 2, 2M, 2X, 2XM, 3, 3M, 3X, and 3XM) are suitable for locations with speed limits of 35 mph or lower, moderate pedestrian volumes, moderate motor vehicle volumes, and up to 4 travel lanes. Examples include urban major collectors and urban minor arterials.
- Devices that require road users to stop (treatment types 4, 4M, 5a, 5aM, 5b, and 5bM) *should* be used at locations where the speed limit is 40 mph or higher, or where the motor vehicle and pedestrian volumes are moderate to high. Such devices *may* be used at locations with speed limits of 35 mph or lower. They are often the preferred treatment for sites with 4 or more lanes, or where visibility issues such as hills, horizontal curves, skew, buildings, or vegetation limit the sight distance for drivers or pedestrians. They are also a good choice for sites with intermittent bursts of pedestrian activity, such as might occur near a school, entertainment venue, or recreational trail crossing. At locations with higher pedestrian volumes, properly configured pedestrian signals can help organize pedestrians into groups that cross at the same time, reducing motorist delay compared with numerous solo crossings. They are typically the preferred treatments for urban and suburban arterials.
- Grade separation (treatment type 6) is mandatory when the facility to be crossed is a freeway or expressway, for example to provide access to a transit station located in the median of a high-speed roadway. Grade separation should be used for crossing other urban roadways if the speed limit is 55 mph or higher. Grade separation is useful in low- and medium-speed applications where high pedestrian volume would cause excessive motorist delay. Subject to local building and zoning regulations and physical clearance requirements, grade separations may also be used to connect related land uses located on opposite sides of a roadway, such as an office building and its parking garage.

What do pedestrians want?

The term “pedestrians” encompasses a very diverse array of road users. Pedestrians range in age from toddlers to the very elderly, and in ability from elite athletes to people who experience extreme pain while walking, or require some type of mobility assistance device. Cities, suburbs, and small towns are increasingly filled with “pedestrians with wheels” such as people pulling wheeled suitcases, delivery drivers maneuvering hand trucks loaded with merchandise, people on roller skates and hoverboards, and users of baby strollers, wheel chairs, mobility scooters and more. If this diversity does not exist and all of the pedestrians observed at a site are young and fit, there is a good chance that site is not meeting the needs of everyone else.

Pedestrian traffic is generated by residences, businesses, schools, employment centers, places of worship, parks, and entertainment venues, along with transit stops, transit stations, and other features of the built environment. The temporal patterns of pedestrian traffic can be very complicated. Around dawn, shift workers and people employed in businesses such as restaurants and hotels are often the main users of pedestrian facilities. A bit later in the morning, there could be a surge of use by schoolchildren. By mid-morning, elderly people might be the primary users. At lunch time, office workers may dominate. In mid-afternoon, the schoolchildren return home. In early evening, there could be an influx of people (and dogs) walking and running for exercise and recreation. After dark, tourists and bar-hoppers in varying states of intoxication could bring a very different set of needs. At all hours of the day and night, motorists turn into pedestrians when they park their cars or get out of a taxi, and transit passengers are transformed into pedestrians the moment they step off a bus or train.

Surveys show pedestrians value safety above all other considerations. In addition, they want to go straight to their destination—they are annoyed and inconvenienced by indirection. This also applies in the vertical direction: steps and ramps are impediments to the free flow of pedestrian traffic, especially if they lengthen the route. Bumps and grade changes are problematic for wheelchair users and other pedestrians with disabilities. Most pedestrians would prefer to cross the street at-grade, ideally with the assistance of a signal. If a grade separation is necessary, pedestrians tend to prefer overpasses (probably because underpasses tend to be gloomy and uncomfortable). Pedestrians—especially those with disabilities—think engineers, city planners, and real estate developers often don't pay enough attention to their needs.

Pedestrian Treatment Selection Factors

Each decision about the appropriate level of pedestrian treatment is site specific. The decision-making process needs to consider both objective (easily quantified) and subjective (hard-to-quantify) factors. A benefit/cost analysis spreadsheet has been developed to help designers identify a minimum treatment level based on motor vehicle and pedestrian volumes, installation cost, and operation and maintenance costs. The spreadsheet is not intended to be definitive: some sites will merit a higher treatment level due to the subjective factors discussed below. If the site meets MUTCD warrants for a mid-block signal, treatment level 4 or higher should be used.

Objective site selection factors include:

- Traffic speed (preferably the actual speed based on a radar/lidar study)
- Motor vehicle volume
- Pedestrian volume
- Device installation cost
- Device operation and maintenance cost
- Site geometrics such as number of lanes, curvature, and visibility (not include in the evaluation spreadsheet)

Subjective factors include:

- Site context such as the degree of urbanization and land use.
- Proximity to pedestrian generators such as bus stops, transit stations, office buildings, hotels, educational institutions, parks, playgrounds, employment centers, and housing.
- Distance to nearest existing signalized or grade-separated pedestrian crossing and extent to which the crossing improvement will reduce pedestrian indirection and delay.
- Demographics of the area near the crossing: people in low-wage occupations tend to walk more than those with higher income, and people ages 12-15 and 60-75 tend to walk the most.
- Frequency of crossing use by highly vulnerable pedestrians such as children, elderly people, and people with disabilities. Consider, for example, the crossing's proximity to facilities such as preschools, schools, medical clinics, and specialized housing for the people with disabilities.
- Presence of unfamiliar road users, such as may occur in tourist/recreational areas.
- Frequency of crossing use by intoxicated pedestrians. Consider, for example, the crossing's proximity to entertainment venues, stadiums, bars, cannabis lounges, and other businesses that allow on-site consumption of intoxicants. Consider the potential for harm

reduction to both intoxicated pedestrians and to others who might be injured as a result of actions by an intoxicated pedestrian or other intoxicated road user.

- Extent to which the crossing is integral to making an area more attractive to pedestrians, e.g., to support the vitality of a neighborhood commercial district.
- Integration with other pedestrian facilities at the neighborhood, city, or regional scale, such as providing access to regional recreational trails.

Obtaining Pedestrian Counts

An estimate of the daily pedestrian volume is required for the evaluation spreadsheet. Pedestrian volume can be estimated based on direct site observation or through video-based traffic counting. Be sure to count on a day that is representative of the typical conditions at the site, avoiding times such as school holidays and periods with severe weather.

For ordinary sites, the daily volume is believed to be about 10 times the volume during the peak hour of pedestrian activity. This figure could differ for sites with atypical pedestrian patterns such as those close to entertainment venues.

A collection of counts for the Las Vegas area is available from the Regional Transportation Commission of Southern Nevada. In addition, many of Nevada’s public transportation systems have installed equipment that automatically counts passengers as they board and alight buses. Since every transit trip begins or ends as a pedestrian trip, these boarding and alighting counts can be treated as a “floor” for the pedestrian count near the corresponding bus stop. In general, it is reasonable to assume that about half of the passengers boarding each bus had to cross the street to reach the bus stop, and about half of the passengers alighting each bus will have to cross the street to reach their ultimate destination.

Pedestrian Treatment Enhancements

Several of the treatment types listed include treatment enhancements. These are briefly defined below.

Raised crosswalks (also called **speed tables**) are speed humps with wide, flat tops. The crosswalk is on top of the raised area. Raised crosswalks are used mainly where the existing speed limit is 35 mph or lower in combination with an unsignalized crosswalk, RRFB, or enhanced amber beacon (EAB). By slowing the traffic, the raised crosswalk increases the likelihood each motorist will yield to pedestrians.

Figure 53. An unsignalized raised crosswalk in Portland, Oregon. Photo: Scott Batson/Wikimedia Commons

Figure 54. Fenced median refuge in Arizona, based on British design. Photo: Arizona DOT

Median refuges are designated pedestrian areas located in the middle of a divided roadway. They allow pedestrians to cross the traffic in two distinct stages. If the available space is sufficient, a median refuge can be combined with any type of unsignalized crosswalk, beacon, or signal.

Median refuges are advantageous to all types of road users. When traffic is moderate to heavy, median refuges reduce pedestrian delay by eliminating the need for pedestrians to wait until both directions are clear of conflicting traffic. This greatly increases the number of times per hour that a pedestrian can safely cross the roadway. Median refuges benefit vehicular traffic by reducing the time spent waiting for pedestrians to cross the roadway. On signalized corridors, median refuges also reduce vehicular delay by making it easier to establish bidirectional traffic signal progression.

Median refuge locations should be selected to minimize pedestrian inconvenience and optimize sight distance. The use of British style fenced, offset median refuges is strongly recommended. By limiting the locations where crossings occur, fenced refuges encourage pedestrians cross at locations with good sight distance and encourage motorists to develop a habit of expecting pedestrians at the designated sites.

The use of offset entries discourages pedestrians from trying to sprint across the entire road. If at all possible, the offset should require pedestrians to turn to the right, so they will be looking at oncoming traffic before they start crossing the second set of lanes. Retroreflective panels, retroreflective tape encircling fence posts, and/or lighting may be used to enhance the conspicuity of the refuge.

Treatment Options for Mid-Block Pedestrian Crossings

Level 0: No Treatment

Unmarked pedestrian crossings are best suited to low-speed roadways with low pedestrian volumes and little motorized traffic, such as minor residential streets. Unsignalized crossings are also ubiquitous on two-lane rural highways at locations where there are very few pedestrians crossing each day.

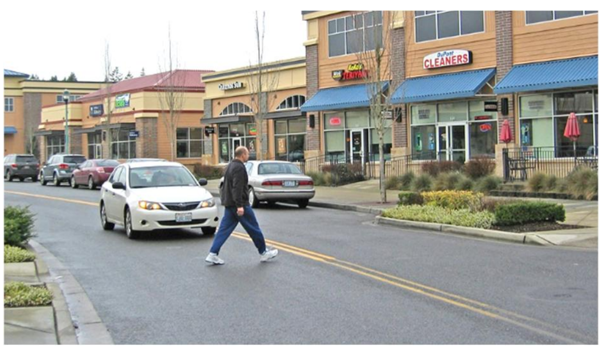

Figure 55. Level 0: unmarked pedestrian crossing in DuPont, WA. Photo: Brett VA/Wikimedia Commons

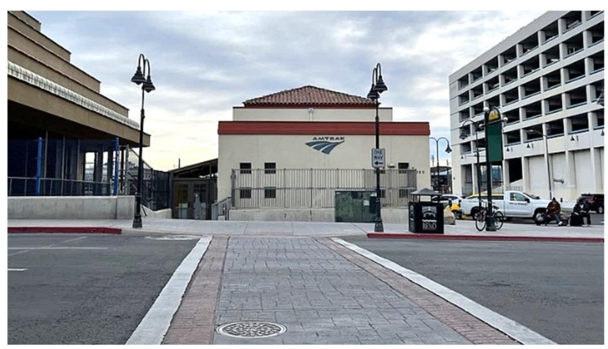

Figure 56. Level 1: unsignalized pedestrian crossing in Reno, NV (Photo: Missvain/Wikimedia Commons CC 4.0)

Level 1: Unsignalized marked pedestrian crossing

The addition of signage and pavement markings to create a marked pedestrian crossing can help encourage pedestrians to cross at locations with favorable grades and visibility. Pavement markings and signage encourage drivers to be more alert for pedestrians at these sites, and this is reinforced to some extent when drivers become accustomed to seeing pedestrians at these locations.

Zegeer (cite) recommended using marked crosswalks under the following conditions:

- Locations with stop signs or traffic signals
- Unsignalized street crossings in designated school zones. Use of adult crossing guards, school signs and markings, and/or traffic signals with pedestrian signals (when warranted) should be considered in conjunction with the marked crosswalk, as needed.
- Unsignalized locations where engineering judgment dictates that the number of motor vehicle lanes, pedestrian exposure, average daily traffic (ADT), posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Level 1X: Unsignalized pedestrian crossing with raised crosswalk (X-walk)

The addition of a raised crosswalk can enhance pedestrian safety by reducing the speed of approaching traffic. This increases the likelihood each driver will yield to pedestrians.

Level 1M: Unsignalized pedestrian crossing with median refuge island

The addition of a raised pedestrian refuge island should be considered for all marked pedestrian crossings of roadways with 4 or more lanes. The provision of a median refuge island is strongly recommended when the annual average daily traffic (AADT) exceeds 12,000 or the speed limit is 40 mph or higher, regardless of the pedestrian volume.

Level 1XM: Unsignalized pedestrian crossing with raised crosswalk and median refuge island

Raised crosswalks and median refuge islands can be combined to further enhance the safety and utility of an unmarked pedestrian crossing.

Level 2: Rectangular rapid-flashing beacon (RRFB)

Rectangular Rapid Flashing Beacons (RRFBs) are a “conspicuity enhancement” activated by a pedestrian pushbutton. The display is comprised of two rectangular yellow LED panels measuring at least 5 x 2 inches. FHWA Interim Approval 21 (2018) requires RRFB assemblies to be used in pairs, one on the left side of the roadway (or in the median) and the other on the right.

Figure 57. Rectangular rapid-flashing beacons (RRFBs) mounted on posts, St. Petersburg, FL (Image: Michael Frederick/pedbikeimages.org [open source])

Figure 58. Rectangular rapid-flashing beacons (RRFBs) mounted on a mast arm, Martin Luther King Boulevard, West Las Vegas, NV (Image: Google Earth)

RRFBs are recommended for pedestrian crossings with the following characteristics:

- Speed limit 35 mph or lower
- No more than 4 traffic lanes
- Low to moderate pedestrian volumes

- Low to moderate motor vehicle volumes

The cost of an RRFB installation is influenced by roadway width. RRFBs are often used on relatively narrow roadways where a post-mounted configuration is sufficient. This allows wireless communication between the pushbuttons and the lighting modules, avoiding the cost of underground wiring. Installation cost will be considerably higher at sites that require overhead mast arms, such as locations where extra width has been paved for future expansion to six travel lanes. Sites with mast arms are likely to require oversize beacons, as well as backplates to improve contrast between the beacons and the sky.

Level 2X: RRFB with raised crosswalk

The addition of a raised crosswalk can enhance pedestrian safety by reducing the speed of the approaching the RRFB. This increases the likelihood each driver will yield to pedestrians.

Level 2M: RRFB with median refuge island

The addition of a raised pedestrian refuge island should be considered for RRFB-equipped pedestrian crossings of roadways with 4 or more lanes and is strongly recommended for at sites where the AADT exceeds 12,000. Refuge islands should also be considered wherever a two-stage crossing will be cost-effective for reducing motorist and pedestrian delays, i.e., the travel time savings over the useful life of the island exceed the cost of installing and maintaining it.

Level 2XM: RRFB with raised crosswalk and median refuge island

Raised crosswalks and median refuge islands can be combined to further enhance the safety and utility of an RRFB-equipped pedestrian crossing.

Level 3: Enhanced Amber Beacon (EAB)

Enhanced amber beacons are pedestrian-activated amber flashing lights that warn motorists of pedestrian presence. The signal heads are larger than an RRFB, using widely-spaced pairs of 8 inch or 12 inch circular signal heads. Typically the lights flash in a wig-wag configuration.

Figure 59. Enhanced amber beacon in Long Beach, CA. Photo: City of Long Beach.

Figure 60. Enhanced amber beacon in Toronto, Ontario (digitally altered to show US MUTCD style signage). Base image: City of Toronto

The California design uses two amber indications, while the Toronto design combines four amber indications with an overhead blank-out sign (YIELD TO PEDESTRIANS) that illuminates when a pedestrian activates the pushbutton. The choice of mounting methods (span wire vs mast arm) is based on local preference (some Toronto installations use mast arms).

An EAB is more conspicuous than an RRFB due to its larger size and more central position in the driver's field of view. The trade-off is higher cost due to the additional infrastructure and underground wiring.

EABs are suitable for sites with intermediate speeds, pedestrian volumes, and motor vehicle volumes, such as major collectors or minor arterials in residential areas.

Level 3X: EAB with raised crosswalk

The addition of a raised crosswalk can enhance pedestrian safety by reducing the speed of the approaching the EAB. This increases the likelihood each driver will yield to pedestrians.

Level 3M: EAB with median refuge island

The addition of a raised pedestrian refuge island should be considered for EAB-equipped pedestrian crossings of roadways with 4 or more lanes, and is strongly recommended for at sites where the AADT exceeds 12,000. Refuge islands should also be considered wherever a two-stage crossing will be cost-effective for reducing motorist and pedestrian delays, i.e., the travel time savings over the useful life of the island exceed the cost of installing and maintaining it.

Level 3XM: EAB with raised crosswalk and median refuge island

Raised crosswalks and median refuge islands can be combined to further enhance the safety and utility of an EAB-equipped pedestrian crossing.

Level 4: Pedestrian signal

As illustrated, pedestrian signals (also known as hawk signals) remain dark to motorists until activated by a pedestrian. Pedestrian signals then display a series of four aspects to motorists: flashing yellow, steady yellow, two steady red lamps illuminated simultaneously, and the two red lamps alternating in a wig-wag configuration similar to a railroad crossing. The motorist signal then goes dark. When the motorist signal is dark, flashing yellow, or steady yellow, the pedestrian signal displays an orange UPRAISED HAND (DON'T WALK). When the motorist signal displays steady red, the pedestrian signal displays a white WALKING PERSON (WALK). When the motorist signal displays the red wig-wag, the pedestrian signal flashes the UPRAISED HAND (DON'T WALK).

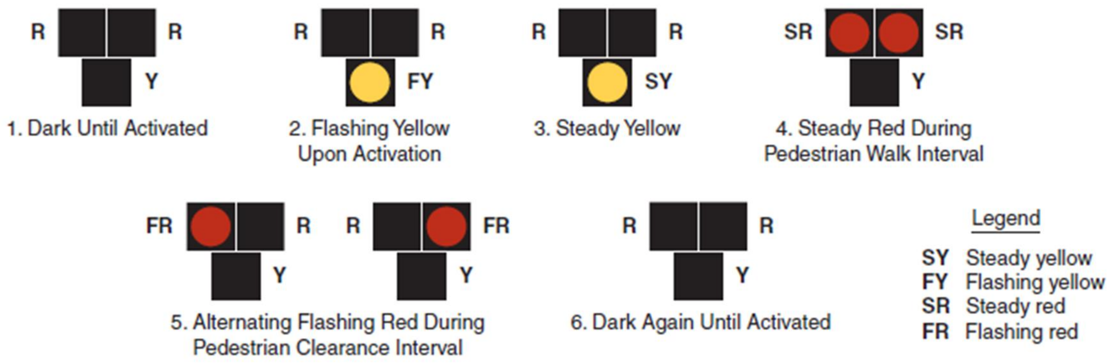

Figure 61. Motorist signal aspects for pedestrian signals.

Pedestrian signals (treatment types 4 and 4M) should be strongly considered for all at-grade midblock crossings with moderate to high pedestrian volume, especially if the roadway speed limit is 40 mph or higher. Pedestrian signals devices *may* be used at locations with speed limits of 35 mph or lower, particularly if the pedestrian volume is high or sight distance problems preclude the use of an RRFB. The presence of a pedestrian signal can help organize pedestrians into groups that cross at the same time, reducing motorist delay compared with numerous solo crossings.

Pedestrian signals are also recommended when pedestrians need to cross four or more traffic lanes, for sites where motorists have difficulty seeing pedestrians or pedestrians have difficulty seeing motorized traffic, and for sites where there are intermittent surges of pedestrian activity that could surprise motorists.

Pedestrian signals should be located at least 100 feet away from a signalized intersection. If desired, the pedestrian signal can be interconnected with a corridor signal system, but this will increase the cost relative to a stand-alone pedestrian signal.

Figure 62. Pedestrian signal in Delaware. Photo: formulanone/Flickr

Level 4M: Pedestrian signal *with median refuge island*

The addition of a raised pedestrian refuge island is strongly recommended for pedestrian signal-equipped pedestrian crossings of multilane roadways. This provides a two-stage crossing that can reduce motorist delay. The addition of a refuge island is strongly recommended for at sites where the AADT exceeds 12,000. Refuge islands should also be considered wherever a two-stage crossing will be cost-effective for reducing motorist and pedestrian delays, i.e., the travel time savings over the useful life of the island exceed the cost of its installation and maintenance.

Levels 5a & 5b: Mid-block pedestrian signal (MPS) or “half signal”

Mid-block pedestrian signals are pedestrian-actuated signals with three-color signal heads. They are ideal for settings where with fairly consistent levels of pedestrian activity, such as shopping districts, or near the entrance to an attraction such as a park, zoo, or museum. Mid-block pedestrian signals are also widely used near elementary, middle, high schools, community colleges, and similar settings.

Level 5 treatments have a somewhat more urban character than Level 4 treatments. They are particularly suitable for locations with extensive visual clutter such as commercial districts, and where sight distance is impacted by buildings, landscaping, parked vehicles, or the like. Mid-block signals are also a good choice for sites with intermittent bursts of pedestrian activity, such as might occur near a school, an entertainment venue, or an alley that functions as a mid-block pedestrian path.

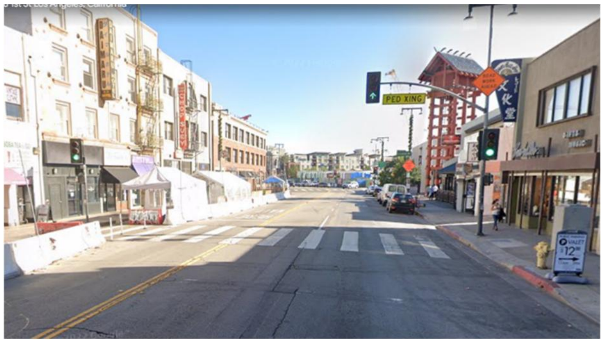

Figure 63. Mid-block pedestrian signal (MBPS), Los Angeles, CA (Image: Google Earth)

Figure 64.Mid-block pedestrian signal, Ames, IA (Image: John Shaw/Iowa State University)

Treatments in the Level 5 series are appropriate when the speed limit is 40 mph or higher, or where motor vehicle and pedestrian volumes are moderate to high. Such devices *may* be used at locations with speed limits of 35 mph or lower. At locations with high pedestrian volumes, properly configured pedestrian signals can help organize pedestrians into groups that cross at the same time, reducing motorist delay compared with numerous solo crossings.

Level 5 treatment is strongly recommended when the crossing meets the MUTCD warrants for a mid-block signal. Alternatively, if the block length is short the pedestrian crossing can sometimes be moved to a nearby intersection that meets MUTCD warrants for an intersection signal.

Treatment level 5a, the Los Angeles design, typically dwells on a steady green arrow (pointing upward), combined with a DON'T WALK indication for pedestrians. When actuated by a pedestrian, the motorist signal switches to steady amber for several seconds, followed by a flashing red indication for motorists and a WALK indication for pedestrians. The signal then returns to the steady green arrow and DON'T WALK indication. Although widely deployed in Los Angeles and its suburbs and occasionally used in other parts of the United States, the device is not mentioned in the 2009 Manual on Uniform Traffic Control Devices (MUTCD). It is under study for wider national use.

Treatment level 5b is a standard traffic signal placed at a mid-block location. In principle, such signals must meet MUTCD warrants, typically Warrant 4 or Warrant 5. For sites with relatively high motor vehicle traffic, Warrant 4 sets the minimum pedestrian volume at 75 to 133 pedestrians per hour, depending on the speed limit, city size, and duration used to measure the pedestrian volume (see the MUTCD for details). Warrant 5 applies to locations within 300 feet of a school "unless the proposed traffic signal will not restrict the progressive movement of traffic." It requires a minimum of 20 schoolchildren during the highest crossing hour, coupled with inadequate gaps in traffic when the children are present. Thus, both warrants tend to favor minimizing motorist delay over maximizing pedestrian safety. As such, they are potentially subject to reconsideration as the Safe System approach becomes more deeply integrated with US traffic engineering practice.

The 2009 MUTCD permits the use of Treatment Level 5b under the following circumstances:

- Where the location meets either Warrant 4, Pedestrian Volume or Warrant 5, School Crossing (the number of adequate gaps in the traffic stream during the period when the schoolchildren are using the crossing is less than the number of minutes in the same period and there are a minimum of 20 schoolchildren during the highest crossing hour).
- Where an exclusive pedestrian phase is provided in one or more directions, with all conflicting vehicular movements stopped, such as the "Barnes Dance" configuration.
- Where there is an established school crossing at any signalized location

- Where engineering judgment determines that multi-phase signal indications (as with split-phase
- timing) would tend to confuse or cause conflicts with pedestrians using a crosswalk guided only by vehicular signal indications

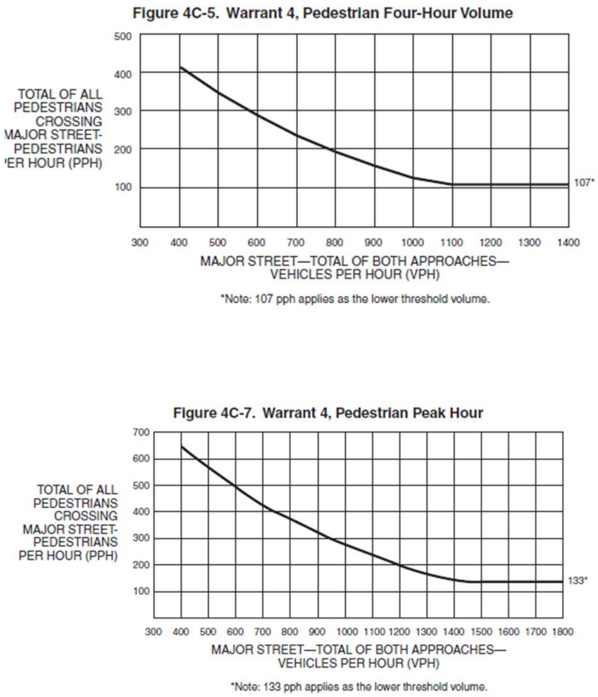

Figure 65. MUTCD Warrant 4 for 4-hour volume (top) and pedestrian peak hour (bottom) (FHWA 2009)

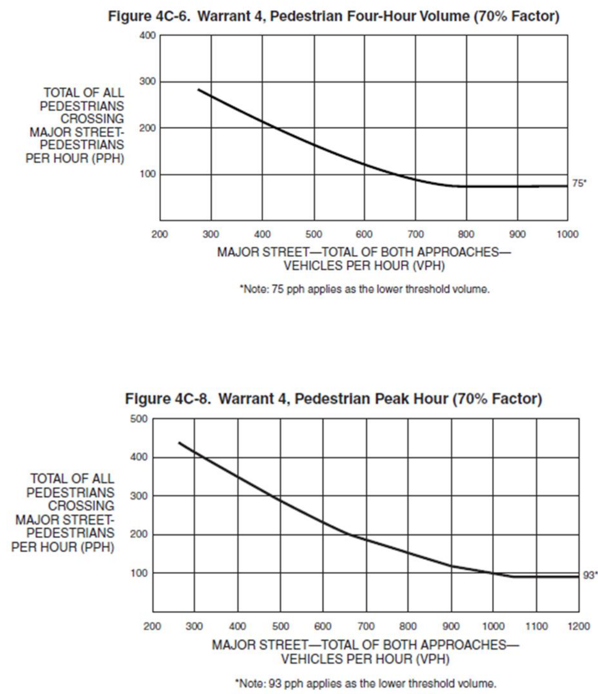

Figure 66.MUTCD Warrant 4 for 4-hour volume (top) and pedestrian peak hour (bottom) for sites with speed limits over 35 mph or communities under 10,000 population (FHWA 2009)

In addition, the MUTCD says Treatment Level 5b *should* be used in the following circumstances:

- It is necessary to assist pedestrians in deciding when to begin crossing the roadway in the chosen direction or if engineering judgment determines that pedestrian signal heads are justified to minimize vehicle-pedestrian conflicts.
- Pedestrians are permitted to cross a portion of a street, such as to or from a median of sufficient width for pedestrians to wait, during a particular interval, but are not permitted to cross the remainder of the street during any part of the same interval.
- No vehicular signal indications are visible to pedestrians, or if the vehicular signal indications visible to pedestrians starting a crossing provide insufficient guidance for them to decide when to begin crossing the roadway in the chosen direction, such as on one-way streets, at T-intersections, or at multi-phase signal operations.

Levels 5aM and 5bM: Mid-block signal with median refuge island

If sufficient roadway width is available, a raised pedestrian refuge island can be combined with the mid-block signal to provide a two-stage crossing. This can reduce delays for both pedestrians and motorists. The use of a refuge island is strongly recommended for at sites where the AADT exceeds 12,000. Refuge islands should also be considered wherever a two-stage crossing will be cost-effective for reducing motorist and pedestrian delays, i.e., the travel time savings over the useful life of the island exceed the cost of installing and maintaining it.

Level 6: Grade Separation (GS)

Grade separations eliminate vehicle-pedestrian conflicts by vertically separating pedestrians from motorized traffic. Although expensive to retrofit to existing sites, they can sometimes be woven into the urban fabric as connections between activity centers on opposite sides of a street. For example, they are sometimes built by private developers to connect real estate holdings located on opposite sides of a roadway, or by a public transit agency to provide access to a transit station located in the roadway median.

The costs of building, operating, and maintaining grade separations vary greatly depending on the span, width, and degree of architectural/aesthetic treatment. In some cases the site geometrics result in a need for ramps or elevators to accommodate people with disabilities.

Figure 67. Pedestrian overpasses can be opportunities for expressions of architectural creativity and civic pride. Right photo: Besopha/Flickr

Figure 68. Colorful artificial windows make the 850-foot pedestrian tunnel connecting O'Hare International Airport concourses B and C more inviting. Photo: InSapphoWeTrust/Wikimedia Commons CC 2.0.

Pedestrian overpasses are often highly visible features of the built environment. When implemented as purely utilitarian structures or equipped with wire mesh cages, they sometimes generate complaints from nearby residents and business owners. In contrast, external architectural features such as arches or trusses can help visually integrate an overpass with nearby properties.

Grade separations that feel harsh or desolate are likely to be disused, especially by women, gender minorities, and elderly people. Where site conditions require an underpass, open sight lines and aesthetic treatments such as artificial windows can make the space feel safer and more inviting.

Grade separation is mandatory when pedestrians are permitted to cross a freeway or expressway, and should be provided if it is necessary for pedestrians to cross a multi-lane highway with a speed limit of 55 mph or greater. At sites that do not meet this speed threshold, the decision to use a grade separation should be based on a benefit/cost analysis that considers the pedestrian and motor vehicle safety risks, pedestrian and motor vehicle delay, and the site-specific life-cycle costs for the grade separation.

Some grade separations are the result of complicated business deals that involve multiple public and private stakeholders. Detailed financial analysis should be performed to establish a fair, equitable, and transparent allocation of upfront costs and the ongoing operation and maintenance of the facility. The analysis should also consider how these costs might be offset by revenue generated by the grade separation, such as increases in land value that result from its presence. Various scenarios may need to be analyzed, such as varying levels of architectural quality and aesthetic treatment.

APPENDIX B

PEDESTRIAN SIGNALIZATION LITERATURE REVIEW

EXECUTIVE SUMMARY

The project team completed a comprehensive review of the pedestrian safety treatment selection and site selection literature. Systematic searches were completed using four scholarly databases (Ebsco Host Academic Search Ultimate, SafetyLit, Transportation Research International Documentation [TRID], and the TRL Library). The searches yielded a total of 167 publications from academic journals and conference proceedings, of which 17 were duplicates. The 150 non-duplicate publications were screened for relevance on the basis of their titles and abstracts, and publications that survived the first screening were subject to full-text review in the second screening. This yielded 29 publications relevant to site selection and treatment selection for mid-block pedestrian crossings, which are summarized in this document. These were augmented with non-academic sources such as national guidelines, and with additional documents found through supplemental searches. Together, the publications serve as a record of the struggle to define pedestrian crossing treatment selection criteria over the past half-century.

Over the years, agencies and researchers have developed selection guidance that ranges from rigid criteria based solely on pedestrian and vehicular volumes, to loose frameworks that ask the analyst to consider a wide range of subjective factors. There is ongoing tension between using criteria that are simple and easy to measure (such as pedestrian counts, vehicle counts, and traffic speeds) and more subjective criteria (such as the adjacent land use, the age and ability level of the pedestrians typically present at the site, and non-traffic policy goals such as promoting walkability to support the vitality of local businesses).

The research suggests a partial mismatch between the selection criteria used by agencies and the factors that concern pedestrians. Specifically, pedestrians tend to think about road crossings in terms of safety, route continuity (ease and directness of access to destinations), and comfort (minimization of delays, ease of use, avoidance of climbing grades/stairs, and so forth). In general, pedestrians tend to prefer signalized at-grade crossings, and are less enthusiastic about unsignalized crossings, overpasses, and underpasses. Pedestrians do not like situations where they are required to double-back to reach their destination. Indirection and grade changes are particularly troublesome for pedestrians with disabilities.

Taken as a whole, the literature suggests a need for a two-phase site selection and treatment selection approach, specifically a planning phase and a design phase. The planning phase involves determining whether the location and spacing of existing pedestrian crossings is adequate, or whether there are unmet pedestrian needs. Some inadequacies are physically observable in the form of a beaten path, or can be identified from crash records indicating a concentration of pedestrian crashes in a specific area. In other cases the locations where pedestrians cross the roadway are diffused along a broad expanse of roadway frontage, but can be channeled into a finite number of crossings. It is also necessary to consider whether pedestrian demand has been suppressed by the difficulty of crossing the roadway.

Planning tools mentioned in the literature include GIS mapping of pedestrian generators (bus stops, schools, shopping areas, major employers, etc.) and prioritization techniques such as the Analytical Hierarchy Process (AHP) and the VIKOR multicriteria selection algorithm. In setting weighting factors for AHP or VIKOR, is necessary to balance the competing priorities of different stakeholder groups. For example, the needs of pedestrians with disabilities differ from those of ambulatory people.

The design phase involves determining the specific location of the crossing, which treatment to apply, and the details of the treatment. Examples include not only the type of crossing treatment, but also whether median refuges will be provided, and whether the pedestrian signal or beacon requires coordination with a corridor signal system.

For single-stage mid-block crossings, the distance from the crossing to the adjacent signalized intersections is crucial for two-way signal progression. The optimal location is not always the midpoint between the two signals, and deviations from the optimal location heavily impact vehicular and pedestrian delay.

The literature identifies many advantages (and very few disadvantages) for using two-stage pedestrian crossings with an offset, fenced median refuge. In general, two-stage crossings are found to:

- Increase pedestrian safety
- Reduce pedestrian delays when crossing busy roadways
- Reduce motorist delays by making it easier to achieve two-way vehicular traffic progression along signalized corridors
- Make it possible to optimize the traffic signal timing plan for two-way progression regardless of the spacing between the mid-block crossing and the adjoining signalized intersections.

Figure 69. Fenced offset median refuge. Typically, the direction of the offset is arranged so that pedestrians will look toward traffic as they make the zigzag. (Photo: Arizona DOT)

Figure 70. Enhanced amber beacon system in Toronto, Ontario, Canada – photo altered to show US MUTCD style signage including overhead blank-out sign. The unretouched image is shown in Figure 93. (Photo: City of Toronto)

The British median refuge design has been optimized for the safety and convenience of all road users. It includes the following features:

- The entry and exit locations of the refuge are offset, and the refuge is fenced, to prevent pedestrians from crossing in a single stage (Figure 69).
- The direction of the offset and the locations of the pedestrian pushbuttons are arranged to force pedestrians to look toward the oncoming traffic (Figure 69).
- In newer designs, the pedestrian signals have been moved to the near side of the crossing, reduced in size, and mounted in the same small box as the pushbutton (Figure 83). Far-side pedestrian signals are eliminated. The DON'T WALK indication appears when the button is pressed, providing visual acknowledgement of the pedestrian signal call. The placement of the box forces pedestrians to continue looking toward approaching traffic while waiting for the WALK indication, and makes the pedestrian signals invisible to motor vehicles to avoid draw-throughs and anticipatory starts. Sites incorporating these features are substantially safer than older designs.

The most crucial design decision is whether the pedestrian assistance device will be red or amber, which is to say, whether a pedestrian signal or mid-block signal will be installed to make it mandatory for drivers to stop at the crossing, or whether motorists will simply be advised to yield to pedestrians by deploying some form of amber warning beacon. The literature points toward the need for traffic on high-speed roadways to be brought to a complete stop, with flashing beacons reserved for low-speed facilities where consequences of a fail-to-yield collision are less severe. Flashing amber devices are unlikely to be satisfactory if the AADT exceeds about 10,000 or the traffic speed exceeds 35 to 40 mph. Grade separation should be considered for sites with very high traffic speed, very high pedestrian traffic, or high motor vehicle traffic.

Several sources discuss numerical thresholds for pedestrian safety treatments, but there is divergence as to what the thresholds should be (Figure 107 and Figure 108 on Pages 138-138). In many cases the rationales for setting existing thresholds do not appear to be well documented. It appears that some of the thresholds were set to minimize traffic delays or limit the cost of installing and maintaining traffic control devices. This focus on vehicular traffic flow and agency costs contrasts sharply with the current national policy of minimizing fatalities and serious injuries.

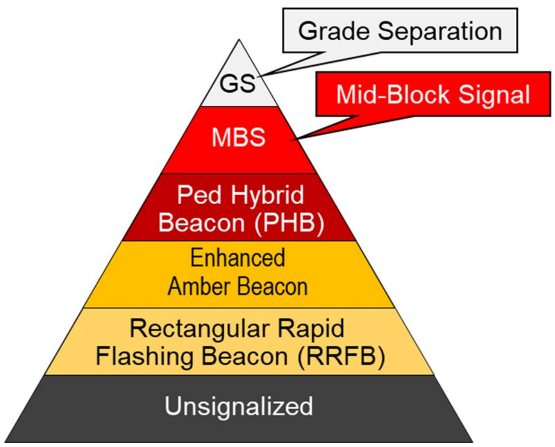

Figure 71. Potential pedestrian crossing treatment hierarchy.

The Canadian guidance is particularly clear in setting out a hierarchy of pedestrian crossing treatments. As volumes grow and operational conditions become more complex, the treatment progresses from a marked crosswalk, to a crosswalk with RRFBs, to a crosswalk with RRFBs and overhead signs, to an enhanced crosswalk with overhead signs and large-diameter amber beacons (Figure 70), to a signalized mid-block crossing. Although pedestrian signals are not part of this hierarchy, they logically fit between the amber-beacon and signalized-crossing stages, and are particularly suitable for high-speed roadways. Similarly, raised crosswalks potentially occupy a niche between the marked crosswalk and the RRFB. While not specifically mentioned in the Canadian guidelines, grade separations (pedestrian overpasses and underpasses) feature prominently in the international research and some of the older American studies. They sit at the top of the hierarchy as the preferred treatment for sites with high traffic speeds or extremely heavy pedestrian or vehicular flows. Figure 71 summarizes this hierarchy concept.

A central quandary presented by the literature is that while treatments such as marked crosswalks, RRFBs, pedestrian signals, mid-block signals, and pedestrian grade separations are implemented primarily as safety treatments, it is difficult to compute pedestrian exposure (and risk) due to the lack of comprehensive pedestrian traffic volume data. Thus, while the safety benefits of specific treatments can be estimated for reactive deployments at high-crash locations, it has been difficult to establish systemic deployment criteria for pedestrian treatments.

This situation contrasts markedly with the protection of railroad crossings, where automatic equipment can be used to count the daily numbers of trains and motor vehicles. As a result, it is easy to compute daily "exposure" by multiplying the two. For decades, exposure-based selection criteria have been used to define a four-step safety treatment hierarchy of "passive" crossings with only signage and markings, "active" crossings with warning lights, gated crossings, and grade separations. Evidence-based selection criteria have established for each treatment level and are broadly accepted by stakeholders. If it is possible to extend this computational logic to vehicle-pedestrian crossings, much of the treatment selection ambiguity could be resolved.

INTRODUCTION

Mid-block crossings are typically used where there is a significant pedestrian desire line distant from an intersection, such as mid-block bus stops, transit stations, parks, plazas, and entrances to schools and other major buildings (NACTO 2013). Various treatments are applied at mid-block crossings, such as crosswalk markings, raised crosswalks, flashing amber beacons, various types of traffic signals, and grade-separation (overpasses or underpasses (Table 23).

Table 23. Pedestrian safety issues addressed by various countermeasures (Blackburn, Zegeer, and Brookshire 2018)

Pedestrian Crash Countermeasure for Uncontrolled Crossings	Safety Issue Addressed				
	Conflicts at crossing locations	Excessive vehicle speed	Inadequate conspicuity/ visibility	Drivers not yielding to pedestrians in crosswalks	Insufficient separation from traffic
Crosswalk visibility enhancement	X	X	X	X	X
High-visibility crosswalk markings*	X		X	X	
Parking restriction on crosswalk approach*	X		X	X	
Improved nighttime lighting*	X		X		
Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line*	X		X	X	X
In-Street Pedestrian Crossing sign*	X	X	X	X	
Curb extension*	X	X	X		X
Raised crosswalk	X	X	X	X	
Pedestrian refuge island	X	X	X		X
Pedestrian Hybrid Beacon	X	X	X	X	
Road Diet	X	X	X		X
Rectangular Rapid-Flashing Beacon	X		X	X	X

*These countermeasures make up the STEP countermeasure "crosswalk visibility enhancements." Multiple countermeasures may be implemented at a location as part of crosswalk visibility enhancements.

Elvik and Høye (2019) combined the results from 15 studies of signal-controlled pedestrian crossings at locations where no pedestrian crossing previously existed. The studies were conducted between 1965 and 2015 in Britain, Western Europe, Australia, Canada, and the US, varying their methodologies and quality. The combined results indicate that signalization reduced the number of pedestrian accidents by 18% (95% confidence interval -42% to +16%), while the number motor vehicle crashes was reduced by 9% (95% c.i. -36% to +29%). When Elvik and Høye corrected for publication bias, the number of pedestrian crashes increased by 6% (-16% to +53%). The possibility that only studies that find reductions in pedestrian crashes are published in the academic literature could be the result of the difficulty of accounting for changes in pedestrian volume after a crossing is installed. Signalizing a crossing is likely to improve mobility, and in some cases this can result in more pedestrian traffic and thus more risk of vehicle-pedestrian collisions.

Table 24. Recommended pedestrian crash countermeasures by roadway feature (Blackburn, Zegeer, and Brookshire 2018)

Roadway Configuration	Posted Speed Limit and AADT								
	Vehicle AADT <9,000			Vehicle AADT 9,000–15,000			Vehicle AADT >15,000		
	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph
2 lanes (1 lane in each direction)	❶ 2 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6 7 9	① 5 6 7 9	① 5 6 ❾
3 lanes with raised median (1 lane in each direction)	❶ 2 3 4 5	❶ ❸ 5 7 9	① ❸ 5 ❼ ❾	① 3 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❼ ❾	① ❸ 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❾
3 lanes w/o raised median (1 lane in each direction with a two-way left-turn lane)	❶ 2 3 4 5 6 7 9	❶ ❸ 5 6 7 9	① ❸ 5 6 ❾	① 3 4 5 6 7 9	① ❸ 5 6 ❼ ❾	① ❸ 5 6 ❾	① ❸ 4 5 6 7 9	① ❸ 5 6 ❾	① ❸ 5 6 ❾
4+ lanes with raised median (2 or more lanes in each direction)	❶ ❸ 5 7 8 9	❶ ❸ 5 7 8 9	① ❸ 5 8 ❾	① ❸ 5 7 8 9	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 8 ❾
4+ lanes w/o raised median (2 or more lanes in each direction)	❶ ❸ 5 6 7 8 9	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 8 ❾

Given the set of conditions in a cell,

- \# Signifies that the countermeasure is a candidate treatment at a marked uncontrolled crossing location.
- ● Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgment at a marked uncontrolled crossing location.
- ○ Signifies that crosswalk visibility enhancements should always occur in conjunction with other identified countermeasures.*

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgment.

1. High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs
2. Raised crosswalk
3. Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line
4. In-Street Pedestrian Crossing sign
5. Curb extension
6. Pedestrian refuge island
7. Rectangular Rapid-Flashing Beacon (RRFB)**
8. Road Diet
9. Pedestrian Hybrid Beacon (PHB)**

*Refer to Chapter 4, 'Using Table 1 and Table 2 to Select Countermeasures,' for more information about using multiple countermeasures.

**It should be noted that the PHB and RRFB are not both installed at the same crossing location.

This table was developed using information from: Zegeer, C.V., J.R. Stewart, H.H. Huang, P.A. Lagerwey, J. Feaganes, and B.J. Campbell. (2005). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: Final report and recommended guidelines. FHWA, No. FHWA-HRT-04-100, Washington, D.C.; FHWA. Manual on Uniform Traffic Control Devices, 2009 Edition. (revised 2012). Chapter 4F, Pedestrian Hybrid Beacons. FHWA, Washington, D.C.; FHWA. Crash Modification Factors (CMF) Clearinghouse. http://www.cmfclearinghouse.org/; FHWA. Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE). http://www.pedbikesafe.org/PEDSAFE/; Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N.J. Thirsk, J. Zegeer, C. Lyon, E. Ferguson, and R. Van Houten. (2017). NCHRP Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Board, Washington, D.C.; Thomas, Thirsk, and Zegeer. (2016). NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways. Transportation Research Board, Washington, D.C.; and personal interviews with selected pedestrian safety practitioners.

Numerous studies have compared the operational and safety performance of unsignalized pedestrian crossings with crossings augmented by devices such as rectangular rapid flashing beacons (RRFBs) or pedestrian signals. To expedite the research these studies often use surrogate measures of safety such as the percentage of drivers who yield to pedestrians. On these metrics pedestrian signals appear to outperform RRFBs in most cases. For example, a recent study of 10 Arizona pedestrian signals found 90% of drivers complied with the steady red indication and 97% yielded to pedestrians (Kay Fitzpatrick et al. 2019). When 186 Arizona pedestrian signals were compared with control sites, crashes were reduced by about 18%.

In spite of the evidence supporting the safety and mobility benefits for various types of pedestrian signals and warning devices, there is a persistent lack of clarity about the site characteristics that are most amenable to each type of treatment. In part, this is because the safety issues addressed by various countermeasures overlap. For example, as shown in Table 24 there are several combinations of lane configuration, traffic volume, and operational speeds where consideration of both RRFBs and pedestrian signals is recommended in a recent FHWA guide (Blackburn, Zegeer, and Brookshire 2018). At sites with wide crossing width, high speed, and high traffic volume, the FHWA guide recommends pedestrian signals, but many such locations also meet warrants for a standard three-color mid-block pedestrian signal, and some could even be candidates for grade separation. The resulting ambiguity can lead to inaction, particularly given the large cost differences between treatment types.

To assess existing site selection criteria for pedestrian signals and warning devices, the project team completed a comprehensive review of publications in academic journals and conference proceedings. The review encompassed four scholarly databases, and except as noted (page 100) was unrestricted as to time and country of publication. The searches yielded 150 unique publications. Among these, 29 were relevant to the present study and several additional sources were found through supplemental searches. The review of academic publications was also augmented with a summary of the guidance provided in the 2009 Manual on Uniform Traffic Control Devices (MUTCD) and FHWA Interim Approval 21 (FHWA 2018).

The 2009 MUTCD and FHWA Interim Approval 21 establish six types of signalized mid-block pedestrian crossings for use in the United States (FHWA 2009). Two designs include a red aspect that requires vehicles to come to a stop before the WALKING PERSON (WALK) indication is displayed to pedestrians:

- **"Regular"** traffic signals. Three-color signals like those used at intersections can be placed at mid-block locations when MUTCD warrants are met.
- **Pedestrian signals**, also known as Hawk signals. As illustrated, these signals remain dark until activated by a pedestrian and then display a series of four aspects to motorists: flashing yellow, steady yellow, two steady red lamps illuminated simultaneously, and the two red lamps alternating in a wig-wag configuration similar to a railroad crossing. The motorist signal then goes dark. When the motorist signal is dark, flashing yellow, or steady yellow, the pedestrian signal displays an orange UPRAISED HAND (DON'T WALK). When the motorist signal displays steady red, the pedestrian signal displays a white WALKING PERSON (WALK). When the motorist signal displays the red wig-wag, the pedestrian signal flashes the UPRAISED HAND.

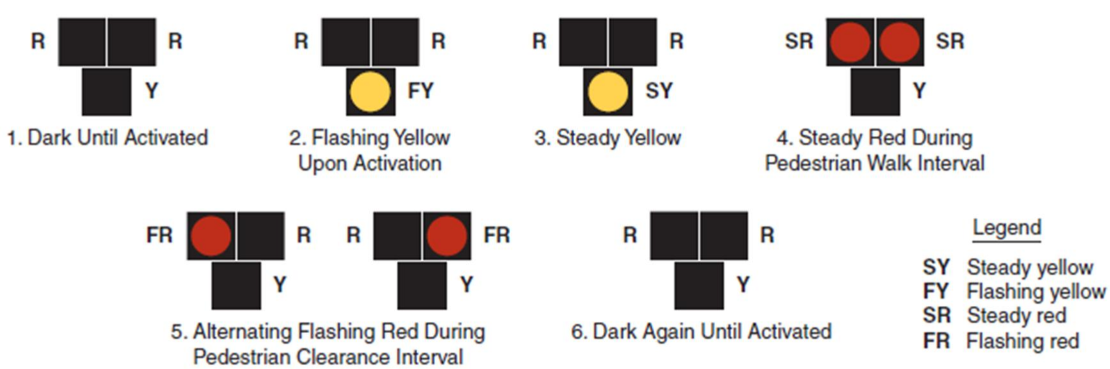

Figure 72. Signal aspects for pedestrian signals.

- Midblock Pedestrian Signal (MPS). A third type of signal is currently under development as an extension of existing practice in the City of Los Angles and other jurisdictions. According to a Request for Proposals issued by the National Cooperative Highway Research Program in 2021, the National Committee on Uniform Traffic Control Devices (NCUTCD) Signals Technical Committee reviewed treatments for several types of midblock pedestrian crosswalks and recommended the use of "Midblock Pedestrian Signals" or MPS. The MPS would operate similarly to a standard semi-actuated vehicular traffic control signal at a midblock crossing, except that it would display a flashing red indication in place of a solid red indication during the pedestrian clearance interval. The MPS concept has been used for more than 40 years in several cities, including Los Angeles. An NCHRP study is currently underway "to summarize the effectiveness of midblock pedestrian signal (MPS) installations and propose language suitable for inclusion in the Manual on Uniform Traffic Control Devices." Terminology note: In Canada, "mid-block pedestrian signals" and the abbreviation MPS refer to standard signals installed at mid-block locations in accordance with MUTCD warrants, not the Los Angeles style device.

The remaining American pedestrian crossing signal designs use flashing amber lights to warn drivers of possible pedestrian presence. As a result, the decision to stop is more-or-less discretionary on the part of the motorist. These designs include:

- **Circular yellow warning beacons**, which can be used "as emphasis for midblock crosswalks." They are typically accompanied by signage facing the motorist that identifies the hazard, e.g., pedestrians. The MUTCD states that such beacons *should* be operated only during those periods or times when the [hazardous] condition exists. Warning beacons that are actuated by pedestrians, bicyclists, or other road users "may be used as appropriate" to provide additional warning to vehicles approaching a crossing or other location. A wide range of yellow warning beacon designs are used in the United States, some with a single flashing light, others with two or more lights mounted either vertically or horizontally.
- **Rectangular Rapid Flashing Beacons (RRFBs)** are a "pedestrian-actuated conspicuity enhancement" comprised of two rectangular yellow LED panels measuring at least 5 x 2 inches. The use of RRFBs is governed by FHWA Interim Approval 21 issued in 2018, which superseded Interim Approval 11 issued in 2008. No site selection criteria are provided in the Interim Approval notice, but RRFB assemblies must be used in pairs, one on the left side of the roadway (or in the median) and the other on the right.
- **In-Roadway Warning Lights.** The use of a series of in-pavement lights to augment the conspicuity of pedestrian crossings is authorized by the MUTCD. This treatment appears to be infrequently used, presumably due to cost and maintenance difficulties.

Existing FHWA Guidance

"Regular" Signals at Mid-Block Locations

The MUTCD permits mid-block applications of "regular" traffic signals under the following circumstances:

- Where the location meets either Warrant 4, Pedestrian Volume or Warrant 5, School Crossing (the number of adequate gaps in the traffic stream during the period when the schoolchildren are using the crossing is less than the number of minutes in the same period and there are a minimum of 20 schoolchildren during the highest crossing hour).

- Where an exclusive pedestrian phase is provided in one or more directions, with all conflicting vehicular movements stopped
- Where there is an established school crossing at any signalized location
- Where engineering judgment determines that multi-phase signal indications (as with split-phase
- timing) would tend to confuse or cause conflicts with pedestrians using a crosswalk guided only by vehicular signal indications

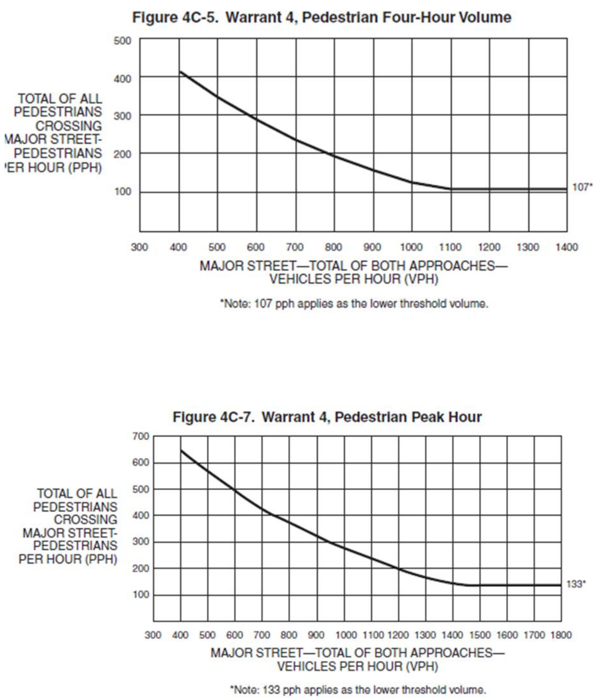

Figure 73. MUTCD Warrant 4 for 4-hour volume (top) and pedestrian peak hour (bottom) (FHWA 2009)

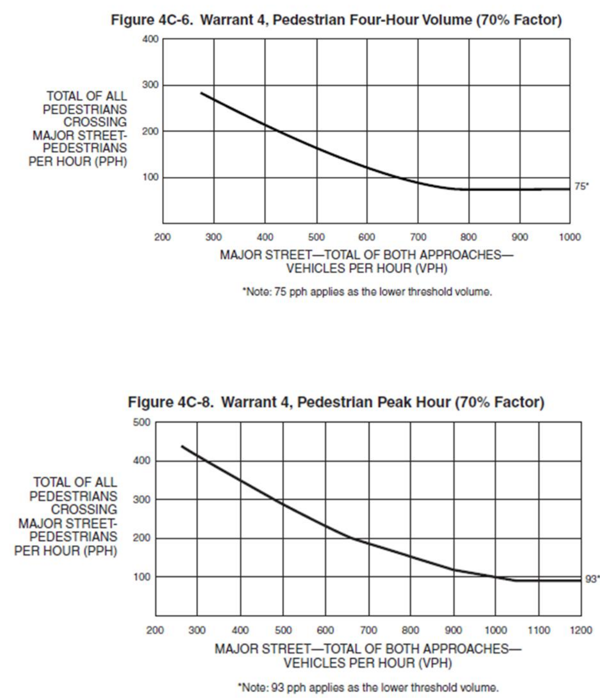

Figure 74.MUTCD Warrant 4 for 4-hour volume (top) and pedestrian peak hour (bottom) for sites with speed limits over 35 mph or communities under 10,000 population (FHWA 2009)

“Regular” traffic signals *should* be used under the following conditions:

- It is necessary to assist pedestrians in deciding when to begin crossing the roadway in the chosen direction or if engineering judgment determines that pedestrian signal heads are justified to minimize vehicle-pedestrian conflicts
- Pedestrians are permitted to cross a portion of a street, such as to or from a median of sufficient width for pedestrians to wait, during a particular interval but are not permitted to cross the remainder of the street during any part of the same interval
- No vehicular signal indications are visible to pedestrians, or if the vehicular signal indications visible to pedestrians starting a crossing provide insufficient guidance for them to decide when to begin crossing the roadway in the chosen direction, such as on one-way streets, at T-intersections, or at multi-phase signal operations.

Pedestrian Signals

The 2009 MUTCD allows pedestrian signals to be installed at any location where pedestrians need assistance crossing, whether the site meets traffic signal warrants or not. It offers the following guidance:

- If a traffic control signal is not justified under the signal warrants [but] the gaps in traffic are not adequate to permit pedestrians to cross, or if the speed for vehicles approaching on the major street is too high to permit pedestrians to cross, or if pedestrian delay is excessive, the need for a pedestrian signal should be considered on the basis of an engineering study that considers major-street volumes, speeds, widths, and gaps in conjunction with pedestrian volumes, walking speeds, and delay.
- The need for a pedestrian signal should be considered if the engineering study finds that the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding total of all pedestrians crossing the major street for 1 hour (any four consecutive 15-minute periods) of an average day falls above the curves shown in the relevant MUTCD nomographs, reproduced here as Figure 75 and Figure 76.

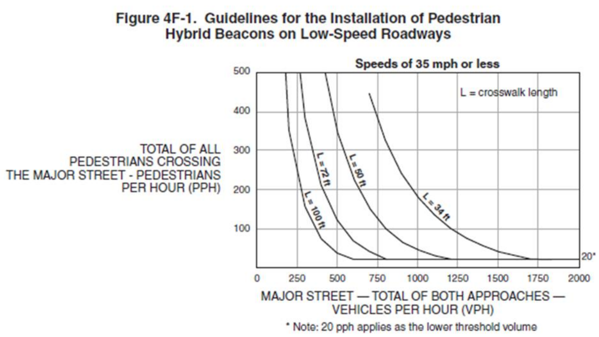

Figure 75. MUTCD pedestrian signal guidelines for low-speed roadways (FHWA 2009)

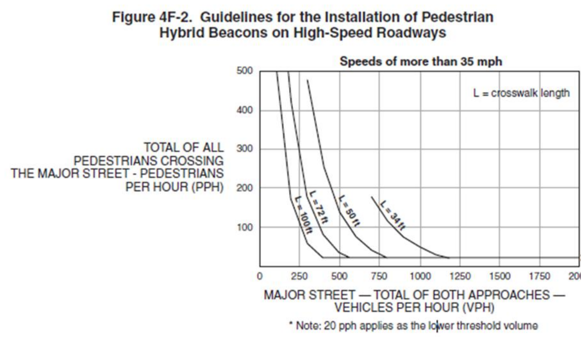

Figure 76. MUTCD pedestrian signal guidelines for high-speed roadways (FHWA 2009)

Yellow Warning Beacons (Circular and Rectangular)

Existing Federal guidance gives agencies broad discretion in the use of circular yellow warning beacons and RRFBs:

- The MUTCD states that circular yellow warning beacons actuated by pedestrians, bicyclists, or other road users “may be used as appropriate” to provide additional warning to vehicles approaching a crossing or other location.
- Interim Approval 21 contains no site selection criteria for Rectangular Rapid Flashing Beacons (RRFBs), but states that the “RRFB shall only be installed to function as a pedestrian-actuated conspicuity enhancement” in conjunction with specific pedestrian, school, or trail crossing signs.

British Mid-Block Pedestrian Signals

Some of the studies found in the literature search refer to British pedestrian crossings or designs derived from British practice. The British standards and guidelines define several types of pedestrian crossings, all named after animals:

- Unsignalized crossings are designated as **Zebra** crossings. As in most US jurisdictions, motorists are legally required to yield to pedestrians approaching or on a zebra crossing, but the actual motorist behavior is inconsistent.
- **Pelican** crossings are actuated by pedestrian pushbuttons. They include a three-color signal for motorized traffic. The pedestrian signals are located on the far side of the crossing, similar to American practice. Pelican crossings display a red STOP indication to motorists during the pedestrian crossing interval, and display flashing amber to motorists during the pedestrian clearance interval. This allows allowing drivers to proceed as soon as all pedestrians have cleared the crossing. Thus, the flashing amber indication used in

the British design serves the same purpose as the flashing red indication that is currently used at pedestrian signals (and proposed for use at MPSs). In the UK the pedestrian-facing aspects are the "red man" (equivalent to the orange UPRAISED HAND in the US) and the "green man" (equivalent to the white WALKING PERSON in the US). Although it was widely used for decades, the Pelican design is now considered obsolete and is being phased out.

- The more recent **Puffin** crossing design also uses a three-color signal for motorized traffic. The pedestrian indicators are located in a small box on the near side of the crossing, which is integrated with the pedestrian pushbutton. As a result, the pedestrian signal lights are seldom visible to motor vehicles. The appropriate pedestrian light (red man or green man) illuminates when the button is pressed, providing a visual acknowledgement of the button activation. Puffin crossings incorporate on-crossing pedestrian radar unit, configured to trigger an extension of the pedestrian interval if any pedestrians have failed to clear the roadway (e.g., dawdling children, people with disabilities, elderly people, or intoxicated people). As a failsafe, the radar units are automatically checked during each motor vehicle phase; if vehicle presence is not detected, subsequent pedestrian clearance intervals are automatically extended to the maximum allowed by the signal timing plan (DfT 2019). Many Puffin crossings also have video detectors to verify that a pedestrian is present at the pushbutton, but this feature (called the kerbside call/cancel detector) is omitted in urban settings with high pedestrian demand. The safety performance of Puffin crossings has been shown to be superior to Pelican crossings, and existing sites are gradually being upgraded to the Puffin design. Puffin crossings cannot be installed within 20 meters (66 ft) of an intersection or roundabout, and reportedly cost approximately £30,000 to £50,000 (USD $40,000 to $65,000) to install (City of Bristol and County of Somerset 2014).
- Specialized British designs include the **Toucan** crossing with separate parallel paths for pedestrians and bicyclists ("two can cross"), and the **Pegasus** crossing for equestrian trails, which has a second set of pushbuttons mounted high enough that the horse rider does not need to dismount.

Figure 77. Pelican crossing in Greenwich, England, 2010 (Photo: Stephen Craven/Wikimedia Commons)

Many Pelican and Puffin crossings in the UK are equipped with pedestrian refuge islands, and the British guidance recommends a staggered (offset) alignment to assure the pedestrian crosses in two distinct stages (Figure 77) (DfT 1995b). The guidance states that a staggered layout “should be considered” when the road width exceeds 11 meters (36 ft) and “should be provided” when it exceeds 15 meters (49 ft). Refuges are fenced to prevent pedestrians from short-cutting the offset, and unless precluded by site conditions the entrance and exit locations are arranged so that pedestrians are looking at the approaching traffic as they walk through the offset (Zegeer 2005). The recommended minimum length of the refuge is 3 meters (10 ft). Actuator buttons for the second stage are located on the downstream side of the offset.

Literature Review Methodology

A considerable body of technical literature has been developed comparing the safety benefits of various pedestrian safety treatments. In general, the results indicate that both RRFBs and pedestrian signals are effective in reducing crashes. Given the lack of definitive deployment criteria in the 2009 MUTCD and Interim Approval 21, the primary issue from a practitioner perspective is determining which of the available devices is the most appropriate for any specific mid-block pedestrian crossing site. Seven distinct options are available to practitioners, listed below in order of increasing cost:

- Unmarked pedestrian crossing
- Signing and marking only (no signals)
- Signing and marking augmented with RRFBs
- Signing and marking augmented with circular yellow beacons
- Pedestrian signal
- Mid-block pedestrian signal (currently being standardized, but already used in cities such as Los Angeles)
- “Regular” traffic signal at mid-block
- Grade separation of pedestrian and motorized traffic

To assist with the development of site selection criteria for Nevada, a comprehensive literature review was conducted. The review encompassed four scholarly databases: Ebsco Host Academic Search Ultimate, SafetyLit, Transportation Research International Documentation (TRID), and the TRL Library (TRL, Limited – formerly the Transport Research Laboratory). The searches were unrestricted as to country of publication, and unrestricted as to time except as noted in Table 25. The searches yielded a total of 167 publications, of which 17 were duplicates. After screening the 150 titles and abstracts, 97 publications were determined not to be relevant to the present study. The project team was able to obtain full-text for 47 of the remaining 50 publications, which was then reviewed to determine relevance to the present study. Based on the full-text review a total of 21 publications were excluded for the reasons shown below:

- Crash modification factors (8 publications)
- Modeling or signal timing (5 publications)
- Surrogate safety measures (4 publications)
- Other (5 publications)

The screening process resulted in 29 publications that provide information about site selection and treatment selection criteria. These, along with several sources found through supplemental searches, are included in the synopsis and synthesis that follows.

Table 25. Literature search criteria

Search Term	SafetyLit	TRID	TRL	Ebsco Host Academic Search Ultimate
("pedestrian signal" OR "hawk crossing" OR "hawk signal") AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants) NOT phenobarbital	✓	✓		
("rectangular rapid flashing beacon" OR RRFB) AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants)	NR	✓		
("pedestrian signal" OR pelican OR "pelican signal" puffin OR "puffin crossing") AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants) NOT ("grade crossing" or "level crossing" OR railroad OR railway)	✓	Limited to publications since 2000		
puffin crossing (manual search)			✓	
pelican crossing (manual search)			✓	
("pedestrian signal OR "hawk crossing" OR "hawk signal") AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants) AND (subject=transportation)				✓
("rectangular rapid flashing beacon" OR RRFB) AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants) AND (subject=transportation)				NR
("pedestrian signal" OR pelican OR "pelican signal" puffin OR "puffin crossing") AND (application OR criteria OR guidance OR guideline OR "site selection" OR warrants) NOT ("grade crossing" or "level crossing" OR railroad OR railway) AND (subject=transportation)	e			NR

Legend	
✓	Completed
NR	No results or results not relevant

CHRONOLOGICAL SYNOPSIS OF STUDIES

Griffiths Griffiths, Hunt, and Cresswell (1976) conducted computer simulations to compare the 1974 British national guidance for the use of Pelican crossings (Figure 78) with the conditions that would result in the lowest overall delays to pedestrians and motorized traffic. In most cases the guidance recommended installation of a Pelican crossing when $\mathbf{PV^2 \geq 100{,}000{,}000}$, where P is the pedestrian flow rate (pedestrians/hour) and V is the motor vehicle flow rate for both travel directions combined (vehicles/hour). Based on the assumption that motorists yield to pedestrians at Zebra crossings as required by British law, Griffiths argued the guidance was too conservative, particularly for two-lane roads; in many cases it would lead to installing a Pelican crossing that would increase delay compared to the yield-to-pedestrian condition at a Zebra crossing. Griffiths also noted that the 1974 guidance did not consider the effects of the motor vehicle traffic directional split on pedestrian and vehicular delay; for example a different threshold might be applicable to one-way streets.

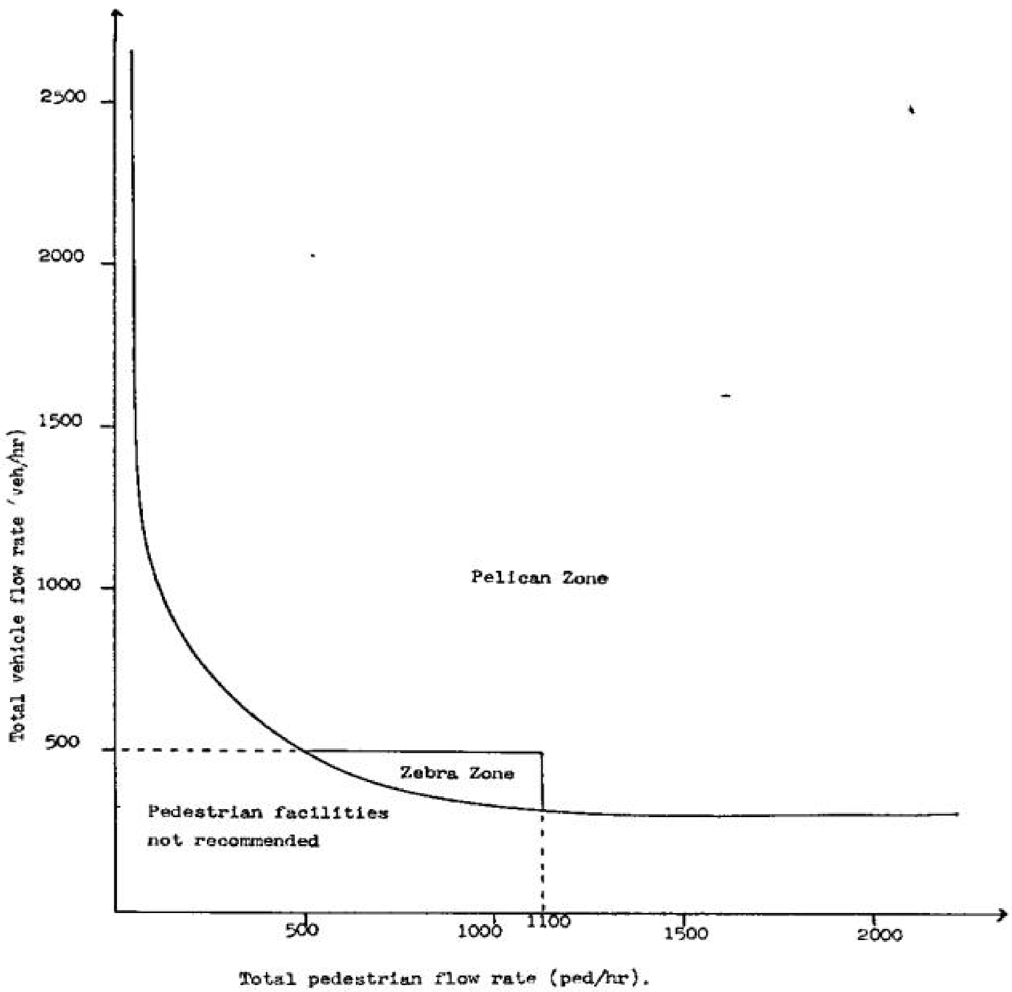

Figure 78. 1974 British guidance for the use of signalized pedestrian crossings.

Axler (1984) developed warrants for grade-separated pedestrian crossings for a research report published by FHWA. After reviewing the criteria used in various jurisdictions and the conflicts between pedestrian needs and grade separation costs, Axler recommended the following warrants:

- “Pedestrian volume should be a total of over 300 in the 4 highest continuous hour period [sic] if vehicle speed is over 40 mph and the proposed sites are in urban areas and not over or under a freeway. Otherwise, pedestrian volume should be a total of over 100 pedestrians in the 4 highest continuous hour period” [elsewhere, the report refers to the 4-hour period with the highest pedestrian volume].
- “Vehicle volume should be over 10,000 in the same 4 hour period used for the pedestrian volume warrant or ADT over 35,000 if both vehicle speed is over 40 mph and the proposed sites are in urban areas. If the two conditions are not met, vehicle volume should be over 7,500 in 4 hours or ADT over 25,000.”
- “A proposed site should be at least 600 feet from the nearest alternative ‘safe’ crossing. A ‘safe’ crossing is where a traffic control device stops vehicles to create adequate gaps for pedestrians to cross. Another "safe" crossing is an existing over- or underpass near the proposed one.”

The report also touches on design considerations such as such as installing barriers to prevent at-grade crossings, lighting and other personal security features, slopes of the pedestrian walkways, and connectivity to adjacent land uses.

Dunn (1989) reported on field experience with unsignalized and signalized pedestrian crossings in New Zealand. Dunn also noted research in Europe and Australia finding that (1) substantially fewer drivers yielded to pedestrians when their approach speed exceeded 50 km/h (31 mph), (2) drivers were more ready to stop when the pedestrian indicated intent to cross with an arm or hand signal, (3) drivers seemed to make their decisions about whether to yield to the pedestrian about 4 seconds before reaching the crossing, and (4) that pedestrian decisions to reject crossing opportunities were also made about 4 seconds before the vehicle reached the crossing.

Dunn stressed the importance of sight distance or “intervisibility distance” between the pedestrian and motorist, particularly at night and at locations where visibility could be obstructed by vegetation, street furniture, or advertising. Based on the combination of field experience and delay minimization computations similar to those conducted by Griffiths, guidance for New Zealand was established stating that Zebra [unsignalized] crossings “are seldom appropriate where the speed limit exceeds 50 km/h (31 mph)...and the vehicle flows are less than 3,000 or more than 10,000 vehicles per day.” (Similar conclusions were reached by Zegeer (2005) based on US data).

The British Department for Transport (DfT) (1995) issued guidance to local agencies on the selection of pedestrian crossing treatments (DfT 1995a). According to the document, examples of the factors most likely to have a bearing on the choice of pedestrian crossing type are:

- **Difficulty in crossing:** the average time that a person normally has to wait at the site for an acceptable gap before crossing, which will differ according to traffic levels, age and mobility.
- **Vehicle delays during peak periods:** the delay is assessed by estimating the number of vehicular stops each minute, and the average duration of each stop, which the crossing flow levels would produce for each of the options.
- **Roadway capacity:** In addition to delays at the crossing, the reduction of roadway capacity may have an effect on the local network.
- **Local representations:** Support or opposition to changes at the crossing from stakeholders such as the police, school administrators, elected officials, and the public.
- **Costs:** the estimated capital cost for installing the crossing, including any impacts on public utilities.
- **Vehicle speeds**

Local agencies are asked to consider options including doing nothing, implementing traffic management or traffic calming measures, installing an unsignalized (zebra) crossing, and installing a signalized crossing. Although no formal benefit/cost analysis is required, the guide includes a two-page worksheet that provides a suggested format for documenting the site characteristics and other factors taken into consideration in the treatment selection decision (Figure 79). A companion guideline discusses design considerations (DfT 1995b).

SITE CHARACTERISTICS

1.1 Site Location	*Description*	
	Ordnance Survey Grid Reference	
1.2 Carriageway Type	*Single*	*Double*
	One Way	*Two Way*
	Number of lanes	
1.3 Carriageway Width		*metres*
1.4 Footway Width		*Side 1 metres*
		Side 2 metres
1.5 Refuge Island		*Yes No*
1.6 Road Lighting Standard		
BS5489 classification		*Category*
Is lighting to above standard?		*Yes No*
Any re-arrangement necessary?		*Yes No*
Better lighting standard needed?		*Yes No*
Supplementary lighting needed?		*Yes No*
1.7 Minimum Visibility		
Pedestrian to Vehicle	*Direction 1*	*metres*
	Direction 2	*metres*
Vehicle to crossing	*Direction 1*	*metres*
	Direction 2	*metres*
1.8 Waiting/Loading/Stopping Restrictions		
At prospective site		*Yes No*
Within 50 metres of the site		*Yes No*
1.9 Public Transport Stopping Points		
At prospective site		*Yes No*
Within 50 metres of the site		*Yes No*
Relationship to crossing [in direction of travel]	*Direction 1*	*approach/exit*
	Direction 2	*approach/exit*
1.10 Nearby Junctions		
Distance to nearest significant traffic junction	*Direction 1*	*metres*
	Direction 2	*metres*
1.11 Other Pedestrian Crossings		
Distance to next crossing	*Direction 1*	*metres*
	Direction 2	*metres*
Type of crossing	*Zebra / Pelican / Puffin / Toucan / Other*	
1.12 School Crossing		
Patrol Distance if less than 100 metres		*metres*
1.13 Skid Risk		
Does surface meet skid resistance requirements		*Yes No*

1.14 Surroundings (entrances within 100 metres)	
Hospital/Sheltered housing/Workshop for disabled people	*Yes No*
School	*Yes No*
Post Office	*Yes No*
Railway/Bus Station	*Yes No*
Pedestrian leisure/shopping area	*Yes No*
Sports stadia/entertainment venue	*Yes No*
Junction with cycle route	*Yes No*
Equestrian centre or junction with Bridle Path	*Yes No*
Others (for example a Fire Station)	

CROSSING TRAFFIC INFORMATION

2.1 Flow and Composition	
Pedestrian count	*number per - - hours*
Prams/pushchairs	*%*
Percent elderly	*%*
Unaccompanied young children	*%*
Severe mobility difficulties	*number per day*
Visually impaired	*number per day*
Crossing cyclists	*number per day*
Equestrians	*number per day*
Others	*number per day*
2.2 Time to cross the road (measured sample)	
Able pedestrians	*seconds*
Elderly or disabled people	*seconds*
2.3 Difficulty of Crossing	
Able pedestrians	
Elderly or disabled people	
(units as for selected method)	
2.4 Latent Crossing Demand	
Estimate	*Unlikely / number per - - hours*

VEHICLE TRAFFIC INFORMATION

3.1 Flow and Composition	
Vehicle count	*number per - - hours*
Cyclists	*number per day*
Heavy goods vehicles	*%*
Public service vehicles	*number per day*
3.2 Vehicle Speed	
85 percentile	*m.p.h.*
Speed Limit	*m.p.h.*

ROAD ACCIDENTS

4.1 Mean Personal Injury Accident Frequency	
Number per year at site (over 5 years if available)	*P. I. accidents/year*
Number per year at an average local site (over 5 years if available)	*P. I. accidents/year*

Figure 79. Treatment selection worksheet from 1995 British guidance (DfT 1995a)

Ribbens (1996) discussed operational and safety problems for pedestrians in South Africa, where was about 80% of all trips were made on foot. As in many other countries, there were operational and safety problems with pushbutton-operated midblock pedestrian crossings. Very often pedestrians pushed the button and then crossed the road against the red pedestrian indication as soon as a gap in the traffic stream was available. When the vehicular traffic stopped, no pedestrians were crossing the road, causing unnecessary delay to motorists coupled with motorist disregard of the red traffic signal. The frequency of rear-end accidents at these crossings was high. In response, Ribbens and his colleagues developed mid-block signal warrants based on motorized traffic and pedestrian characteristics such as the width to be crossed, one-way vs two-way motor vehicle traffic, speed limit, and pedestrian walking speed for different age groups.

The group evaluated British-style Pelican signals in the South African context. In contrast to the mid-block signals used previously, the Pelican displays a flashing amber signal after the red STOP indication, thus allowing drivers to proceed as soon as all pedestrians have cleared the crossing. Results showed that vehicular delay was substantially reduced at the Pelican crossings, the number of pedestrian crashes was reduced, and the number of rear-end crashes reduced substantially.

Ribbens also presented warrants for grade-separated pedestrian crossings on urban arterials. Selection criteria included the number of lanes, one-way vs two-way motor vehicle traffic, signal cycle length, hourly vehicular volumes, and number of pedestrians per hour. Traffic volume warrants ranged from 3675 to 5000 vehicles per hour and pedestrian volume warrants ranged from 2125 to 2800 pedestrians per hour, depending on the number of lanes and cycle length. Ribbens asserted that grade separation is a suitable alternative to a signal-controlled crossing only when the cycle length of the signalized crossing exceeds 110 seconds.

Cottrell et al. (2004) developed guidelines for various pedestrian crossing safety features through a literature review and a review of actions taken and tested in several cities. The study included a review of warrants for grade-separated pedestrian crossings, from which Cottrell synthesized the following proposed guidance for Utah:

Quantitative Criteria

- There is no alternative crossing within 150 m (490 ft) of the candidate location.
- The existing or anticipated pedestrian crossing volume exceeds: 100 in 4 hours if the crossing barrier is a freeway, river, canal, railroad, or other impedance, OR 300 in 4 hours if the crossing barrier is a surface street
- For crossings of surface streets, the 85th percentile motor vehicle speed exceeds 40 MPH AND the average daily traffic (ADT) exceeds 35,000 AND there is no raised median or pedestrian refuge AND wore than four lanes must be crossed, including turning lanes
- IF pedestrian volume data are not available OR in lieu of pedestrian volumes, consider a grade separated crossing IF, along a 300 m (980 ft) road segment with no crossing facilities, there have been three or more pedestrian-vehicle crashes in ten years, two or more pedestrian-vehicle crashes in five years, OR two more pedestrian-vehicle crashes in three years.

Qualitative Criteria

- The crossing would serve a well-defined origin-destination pair, such as a school and a residential area, a parking facility and a shopping center, a neighborhood and a park, a transit stop and a campus, etc. AND
- There is a need to prevent or offer an alternative to at-grade crossings OR
- There are natural or man-made barriers to pedestrian crossings OR
- Alternative crossing routes are long and circuitous OR
- There is community support for a grade-separated crossing

Kay Fitzpatrick (2003); K. Fitzpatrick, Carlson, and Institute of Transportation (2004); Kay Fitzpatrick et al. (2006) developed updated pedestrian signal warrants and guidelines that can be used to select pedestrian crossing treatments for unsignalized intersections and mid-block locations. The report, published as NCHRP 562, included worksheets and diagrams for selecting situationally-appropriate pedestrian treatments. Treatments were placed in four groups:

- **Enhanced.** Devices that enhance the visibility of the crossing location and pedestrians waiting to cross. Warning signs, markings, or beacons in this category are present or active at the crossing location at all times, such as yellow warning lights that flash continuously.
- **Active.** Also called "active when present," this category includes those devices designed to display a warning only when pedestrians are present or crossing the street, such as RRFBs.
- **Red:** Devices that display a circular red indication (signal or beacon) to motorists at the pedestrian location, such as pedestrian signals.
- **Signal.** Traffic control signals meeting MUTCD warrants.

A series of nomographs such as Figure 80 and Figure 81 presented treatment selection criteria based combinations of traffic speed, crossing width, presence of median refuge, motorist behavior (classified as either high-compliance or low-compliance) and total daily pedestrian delay computed as a function of pedestrian volume and motor vehicle volume. A set of warrant analysis worksheets was also prepared (Figure 82). The use of pedestrian signals was recommended for all high-volume locations, and for moderate-volume locations with poor motorist compliance.

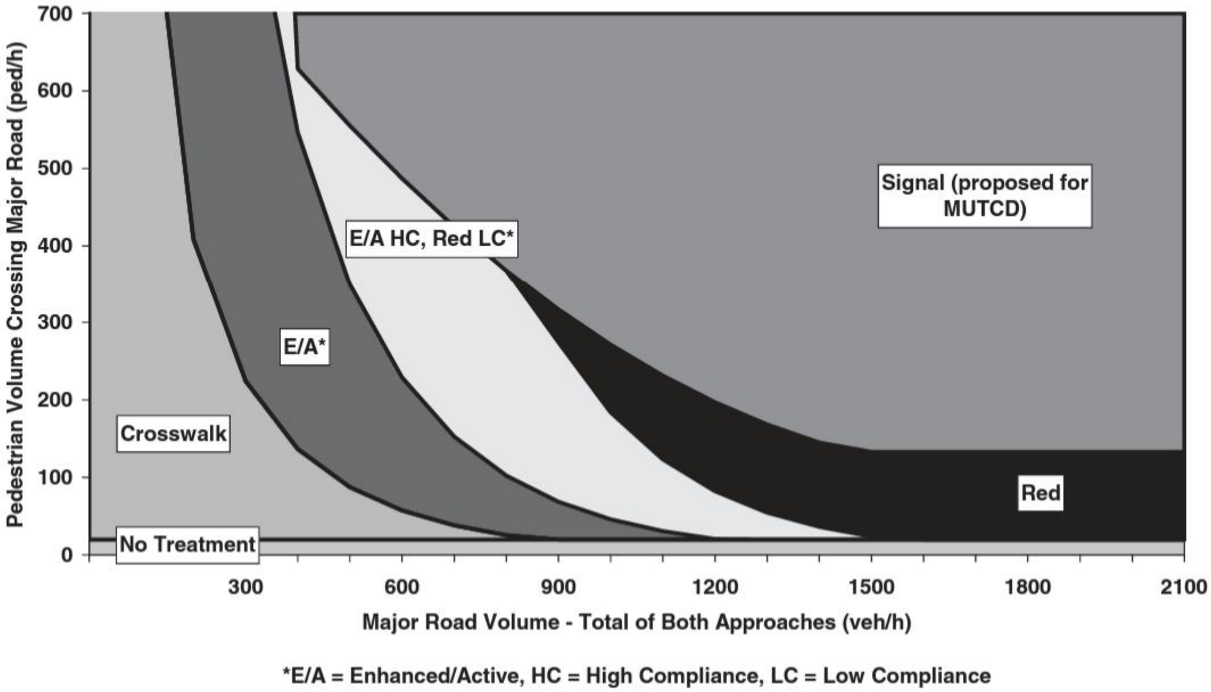

Figure 80. Treatment selection guidelines proposed by Fitzpatrick for a 50 foot (17 m) pavement, speed less than 35 mph (55 km/h) and 3.5 ft/s (1.1 m/s) walking speed (Kay Fitzpatrick et al. 2006)

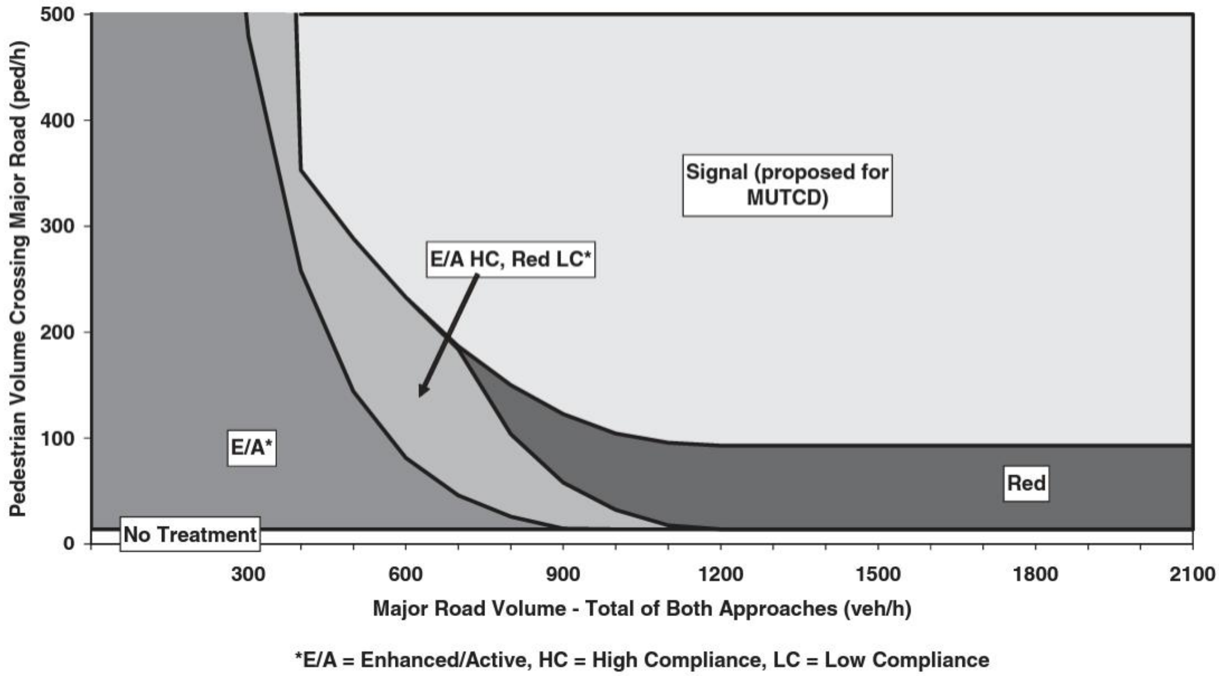

Figure 81. Treatment selection guidelines proposed by Fitzpatrick for a 50 foot (17 m) pavement, speed greater than 35 mph (55 km/h) and 3.5 ft/s (1.1 m/s) walking speed (Kay Fitzpatrick et al. 2006)

In an appendix, Fitzgerald et al compared the pedestrian crossing signalization guidelines for various US and foreign jurisdictions. The criteria ranged from very general to very specific. For example:

- A guideline from the City of Sacramento (California) proposes the installing overhead flashing beacons or similar devices on two-lane streets with 35 mph speed limits and traffic volumes over 15,000 vehicles per day, and all crossings of streets with speed limits of 40 mph or greater.
- Factors included in the Transportation Association of Canada guidance included pedestrian traffic volume and crossing opportunities (traffic gaps) per hour. Pedestrian volume thresholds were lower in communities with smaller populations; for example the use of a pedestrian signal was deemed appropriate when there were less than 60 crossing opportunities per hour AND the pedestrian volume reached 50 pedestrians/hour in communities with less than 10,000 population; 55 pedestrians/hour in communities of 10,000 to 250,000 people, and 60 pedestrians/hour is communities with populations of 250,000 or more.
- Guidelines for local agencies in the United Kingdom issued in 1995 require consideration of a variety of factors such as number of lanes, one-way vs two-way traffic flow, lighting, sight distance, parking arrangements, presence of bus stops, distance to nearest intersection, pavement skid resistance, land use, composition of the pedestrian traffic stream (e.g., highly vulnerable users such as elderly people), traffic volumes, and prior crash history. The guidance does not provide specific warrants, criteria, or benchmark. Staff from the Department of Local Government Transport and the Regions stated they specifically avoided using numerical values because they want guideline users to employ engineering judgment in the final decision on whether to install a particular type of crossing.

- New Zealand guidance used thresholds based on the number of pedestrians multiplied by the number of vehicles.

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), $d_p = (e^{v\,tc} - v\,t_c - 1)/v$ 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 82. Mid-block pedestrian treatment warrant proposed by Kay Fitzpatrick et al. (2006).

- Guidance for mid-block crossings in the state of Victoria, Australia (which includes Melbourne, the country's second-largest city) was based on the functional classification of the roadway. In general, pedestrian-actuated signals were "likely to be appropriate" on roadways classified as primary major or secondary major, and mid-block pedestrian crossings with flashing lights "may be appropriate" on collectors. Further, pedestrian operated signals were recommended when the pedestrian volume during any hour of an average weekday exceeds 100 and vehicular volume exceeds 500 for an undivided roadway or 1000 for a roadway with a median, or where there is a need for coordination with a nearby traffic signal, a visibility problem, or a record of two or more pedestrian crashes within the previous 3 years.

Baranowski (2005) reviewed existing and proposed criteria for pedestrian crossing signals at the approaches to roundabouts. He noted the US Access Board's advocacy of the signals, but expressed doubts about whether the traffic conditions at roundabout approaches were comparable to mid-block pedestrian crossings. Baranowski compared the mid-block signalization criteria used in various jurisdictions and provided several application examples for roundabouts with high pedestrian volumes. For example, a signalized mid-block pedestrian crossing about 150 feet downstream of a roundabout exit near the University of Utah campus in Salt Lake City was noted to cause serious but brief backups into the roundabout.

Halden (2005) discussed the experiences of small communities in the West Lothian area of Scotland, based on a 2004 pedestrian crossing performance review commissioned by the West Lothian Council. Forty-five signalized crossings and 24 zebra (unsignalized) crossings had been installed starting in the mid-1990s, mainly in small-town business districts. Zebra crossings were felt to be suitable where pedestrian flows are low, traffic flows are light, and speeds are low. Signalized pedestrian crossings were felt to be justified when traffic speeds were high, high pedestrian flows created unacceptable delays for vehicles, or there were above-average numbers of elderly pedestrians or people with disabilities. A comparison of two adjacent sites confirmed that average delay per pedestrian was substantially higher at the signal than at the nearby zebra crossing. Although signalized pedestrian crossings were likely to increase delays for both motorists and pedestrians, their traffic calming effect was felt to improve the environment of business districts, encourage people to shop locally, and support the business district's economic viability, especially when used in combination with other traffic calming measures. Pedestrian treatments were particularly important on routes providing access to schools and train stations.

Walker et al. (2005) compared the safety, efficiency, and operational characteristics of Puffin crossings with the older Pelican design. The study used matched pairs of crossings: five Puffins and five Pelicans, all in London. Each pair was in the same neighborhood of the city.

The Puffin was designed as an improvement on the Pelican crossing, offering advantages to both pedestrians and drivers. The intended advantages include:

- Inclusion of a pedestrian detection radar unit that calls an extension of the pedestrian interval for pedestrians who move slowly or start to cross late in the GREEN MAN (WALK) phase
- The ability to cancel a pedestrian call if no pedestrian is detected at the curbside
- Elimination of the FLASHING AMBER/FLASHING GREEN MAN phase (analogous to the FLASHING DON'T WALK interval in North America)
- Introduction of a near-side pedestrian indicator upstream of the crossing, replacing the pedestrian signals on the far side of the intersection. This is intended to encourage pedestrians to look toward approaching traffic and keep the RED MAN (DON'T WALK) in their field of view when it is no longer appropriate to start crossing.

Figure 83 illustrates the hardware for a typical puffin crossing. The right photo shows the integrated pedestrian pushbutton/pedestrian signal module, mounted on the near side of the crossing. It is positioned so that pedestrians pushing the button face the approaching traffic (facing to the right in the one-way street example shown in the photo). In most cases this module is not visible to motorized traffic, and can only be seen by pedestrians who are making a decision about whether to begin crossing or not. In the left photo, note the diagonally-mounted radar unit above the signal head, which is used to determine whether a pedestrian interval extension is required due to a pedestrian who remains on the crossing when the pedestrian phase is about to terminate. Also note the downward-mounted curbside pedestrian detector, which is used to determine whether the pedestrian is already gone and the pedestrian pushbutton call can be cancelled.

Figure 83. Typical puffin crossing and near-side pedestrian signal module with pushbutton

Figure 84 shows the timing sequence for a Pelican crossing, and Figure 20 shows the sequence for a Puffin crossing.

	A	B	C	D	E	F	G
Vehicle Signal	Green	Steady Amber	Red			Flashing Amber	
Vehicle Instruction	Proceed if clear	Stop if safe	Wait at stop line			Give way to peds	
Pedestrian Signal	Red			Green	Flashing Green		Red
Pedestrian Instruction	Wait			Proceed if clear	Do not start to cross		Wait

Figure 84. Pelican crossing timing sequence.

	1	2	3	4	5	6	7	8	9
Vehicle Signal	Green	Amber	Red						Red Amber
Vehicle Instruction	Proceed if clear	Stop if safe	Wait at stop line						Wait at stop line
Pedestrian Signal	Red			Green	Red	Ext. Red	Red		
Pedestrian Instruction	Wait			Proceed if clear	Do not start to cross	Do not start to cross	Do not start to cross		

Figure 85. Puffin signal timing sequence

Walker et al collected 12 hours of video data at each site, but the number of observed pedestrian-vehicle conflicts was too small to determine whether the Puffin crossing was safer than its predecessor. Elimination of the FLASHING GREEN pedestrian phase (analogous to the FLASHING DON'T WALK phase in North America) significantly reduced the number of pedestrians who started to cross late in the pedestrian interval. Overall, about half of all pedestrians crossed without activating the pushbutton; this was more likely at sites with long cycle lengths, and particularly prevalent near the Euston commuter rail station. At the sites studied, the call cancel feature was rarely needed. Other differences in the observed pedestrian and vehicle behavior appeared to be mainly related to signal timing and other site-specific factors rather than the type of signal.

Zegeer (2005) analyzed crash data from 1000 marked and 1000 unmarked pedestrian crosswalks in the United States. Although the primary aim of the study was to understand how crosswalk markings affect pedestrian crash rates, the analyses showed that the frequency of pedestrian crashes increased with higher pedestrian volumes, higher traffic volume, and a greater number of lanes (i.e., multilane roads with three or more lanes had higher pedestrian crash rates than two-lane roads). The presence of a raised median or raised crossing island was associated with a significantly lower pedestrian crash rate at multilane sites with both marked and unmarked crosswalks.

For average daily traffic (ADT) volumes of about 10,000 or less, pedestrian crash rates were about the same between marked and unmarked crosswalks (less than 0.25 pedestrian crashes per million pedestrian crossings). For ADTs greater than 10,000, the pedestrian crash rate for marked crosswalks became increasingly higher as the ADTs increased, while the pedestrian crash rate at unmarked crossings increased only slightly with increasing ADT.

Based on these findings, Zegeer concluded that a marked crosswalk alone is usually insufficient for pedestrian crossings on high-volume roadways. Under such conditions, more substantial improvements such as refuge islands, an RRFB, or a pedestrian signal are often required to increase the likelihood of motorists stopping and yielding. Zegeer also recommended reducing vehicle speeds and shortening the crossing distance where feasible.

Zegeer recommended using marked crosswalks under the following conditions:

- Locations with stop signs or traffic signals
- Unsignalized street crossings in designated school zones. Use of adult crossing guards, school signs and markings, and/or traffic signals with pedestrian signals (when warranted) should be considered in conjunction with the marked crosswalk, as needed.
- Unsignalized locations where engineering judgment dictates that the number of motor vehicle lanes, pedestrian exposure, average daily traffic (ADT), posted speed limit, and geometry of the location would make the use of specially designated crosswalks desirable for traffic/pedestrian safety and mobility.

Zegeer stated that marked crosswalks alone (i.e., without traffic-calming treatments, traffic signals and pedestrian signals when warranted, or other substantial crossing improvement) are insufficient and should not be used under the following conditions:

- Where the speed limit exceeds 40 mph
- On a roadway with four or more lanes without a raised median or crossing island that has (or will soon have) an ADT of 12,000 or greater
- On a roadway with four or more lanes with a raised median or crossing island that has (or soon will have) an ADT of 15,000 or greater

Penna de Araujo and de Camargo Braga (2008) compared pedestrians' perceptions of the quality of four signalized pedestrian crossings in São Paulo, Brazil with the level of service (LOS) results from the 2000 Highway Capacity Manual. São Paulo has a high pedestrian mode share (around 35% of total daily trips in 1997), but the city's street network was designed primarily for motorized traffic. The study began with a list of 60 technical attributes of pedestrian crossings that could potentially be treated as performance measures for pedestrian crossings (Table 26). These were then grouped into three main categories:

- Comfort: waiting time, space available while waiting to cross, number of pedestrians, one-way or two-way street, state of the road surface
- Safety: road width, vehicle speed, visibility (being able to see vehicles and be seen), lighting conditions, guardrails
- Continuity: absence of obstacles such as street vendors in the walkway, good state of repair, appropriate curb height, presence of median refuge

Using a paired-comparison questionnaire, 424 pedestrians were surveyed on their priorities. Among the three categories, pedestrians strongly prioritized safety over both continuity and comfort, and somewhat prioritized continuity over comfort. These views were affirmed when the pedestrians were asked to rate four signalized crossings in different parts of the city: although the 2000 HCM level of service metric for pedestrian crossings is delay (classified as a comfort metric in the study), safety appears to have been more influential in the participants' ratings of the crossings. Nevertheless, the authors expressed concerned that ratings may have also been influenced by the overall quality of the built environment at each of the four sites (including surrounding buildings and land uses), rather than just the characteristics of the crossings themselves. Thus, there may be a greater tolerance for pedestrian delay at the crossing if the overall environment is perceived as safe, orderly, and well-organized.

Table 26. Attributes of pedestrian crossings considered as potential performance measures by de Araujo and de Camargo Braga (2008)

Category	Attribute
Road and traffic operations	Road hierarchy, road width, visibility (being able to see vehicles and be seen), turning movements, gradient, horizontal curves, lighting, channeling of pedestrian flow, state of upkeep of the road surface, bus lane, one-way or two-way street, rumble strips, central island width, drainage, parking, taxi stop, bus stop, speed humps, central island/refuge
Pedestrians	Pedestrian volume, pedestrian desired route, type of pedestrian in relation to land use/activities, land use/local activities, demand (in time and space), security, pedestrian speed, waiting time/delay
Vehicles	Speed, density, volume, proportion of vehicle types
Road markings and signs	Zebra crossing, stop line, zebra crossing length, maintenance, signs warning of the presence of zebra crossing, signs orientating and warning pedestrians, additional information for pedestrians, markings preventing lane changing by vehicles
Traffic lights	Pedestrian lights, vehicle lights, timings for pedestrians, timings for vehicles, cycle, Pelican crossing, visibility of pedestrian lights, variable cycle
Sidewalks and central islands	Absence of obstacles, guard-rail/barrier, lowered curb, potholes/state of upkeep of sidewalk, street vendors, sidewalk/central island width, building alignment, gradient, curb side height, sidewalk material
Others	Visual intrusion, fiscalization (sic), staff orientating pedestrians when to cross

Diogenes and Lindau (2010) analyzed the safety of 21 marked and unmarked mid-block pedestrian crossings in Porto Alegre, Brazil. Multi-stage crossings with refuge islands were found to have lower crash rates than single-stage crossings, and signalized crossings had lower crash rates than unsignalized crossings. Conversely, the presence of bus stops and busways increased pedestrian crashes, though this effect was attenuated at locations the highest levels of transit service (possibly because those locations were more congested, and thus had lower traffic speeds).

Šimunović, Grgurević, and Pašagić Škrinjar (2010) explored objective methods for determining whether a pedestrian crossing should be unsignalized, signalized, an overpass, or an underpass. Recognizing that such decisions often involve trade-offs between conflicting objectives, they compared the priorities of four stakeholder groups: traffic experts, real estate investors, people with disabilities, and the general public. The resulting survey data was used to establish weighting factors that could be applied in a multi-criteria decision framework using the analytical hierarchy process (AHP), and to identify each group's preferred crossing types.

To establish weighting factors, the group conducted paired-comparison surveys of four sets of stakeholders: 10 traffic experts, 10 real estate entrepreneurs, 10 people with disabilities (6 wheelchair users and 4 blind people), and 100 healthy members of members of the general public (mixed ages and genders). Although not explicitly stated in the publication, it appears that all participants were from Zagreb, the capital city of Croatia, which had a population of 790,000 at the time of the survey.

The selection criteria were grouped into four categories:

- Safety: traffic speed, traffic volume, and crossing length
- Energy: level of physical effort required for the pedestrian, including the effects of indirection and climbing stairs or ramps
- Price: cost of design, construction, and maintenance
- Other: noise, environmental impact, access for people with disabilities, and comfort (aesthetics, sense of personal security, and ease of understanding how the crossing connects to adjacent areas)

As shown in Table 27, the four groups had very different priorities. Although all groups gave high importance to safety, real estate investors put heavy emphasis on cost and almost none on energy (indirection and the personal effort required to climb steps or ramps). Conversely, people with disabilities put heavy emphasis on energy and very little on cost.

Table 27. Comparison of stakeholders' weighting factors for multi-criteria decision-making framework.

Criterion	Traffic Experts	Real Estate Investors	People with Disabilities	General Public
Safety	51.4%	38.7%	41.0%	48.7%
Energy	5.9%	4.4%	21.8%	5.0%
Price	25.9%	45.9%	4.9%	24.8%
Other	16.8%	11.0%	32.4%	21.5%

Given these differences in priorities, the preferred type for a generic crossing also differed for each group:

- Traffic experts preferred underpasses and overpasses about equally, and ranked signalized crossings third, with at-grade pedestrian crossings as the least-preferred type.
- Real estate investors preferred at-grade pedestrian crossings, ranked signalized crossings second, overpasses third, and scored underpasses as the least-preferred type.
- People with disabilities strongly preferred signalized at-grade crossings. They ranked unsignalized crossings a distant second, underpasses third, and overpasses as their least-preferred type.
- The general public preferred signalized at-grade crossings. They ranked unsignalized at-grade crossings second, underpasses third, and overpasses as the least-preferred type.

Gitelman et al. (2012) reviewed the characteristics and locations of pedestrian fatalities and injuries in Israel, which has a higher pedestrian crash rate than most industrialized countries. Comparisons of crash characteristics were used to identify 10 typical pedestrian crash patterns, representing different combinations of degree of urbanization, roadway type, intersection vs mainline, and community demographics.

About three-quarters of the pedestrian casualties occurred at unsignalized mid-block crosswalks, or at locations without crosswalk markings. These sites were mainly in urban areas with predominantly Jewish or mixed Jewish and Arab population. Small- and medium-sized towns with predominantly Arab populations had high rates of crashes involving children, along with considerable numbers of crashes involving pedestrians who were crossing divided highways. As a result, per capita casualty rates were 26% higher among the Arab minority. For the population a whole, people over 65 were overrepresented amongst those killed or injured. Among all age groups, men were overrepresented in fatality cases and women were overrepresented in injury cases.

More than 60 pedestrian crossing safety measures were identified based on international experience, ranging from traffic calming treatments to signalization and grade separation. Many of the treatments were not in use, or only rarely used, in Israel. For example, signalized mid-block crossings were believed to be used in less than 20% of Israeli towns.

A total of 75 high-crash locations in 14 towns were selected for in-depth review. Most sites were in city centers. Field reviews indicated that on a micro-level, most sites had no major design deficiencies. More subtly, the designs were often vehicle-centric, contributing to operational issues such as speeding, excessive pedestrian delays, conflicts between pedestrians and turning vehicles, and illegal parking that affected pedestrian visibility.

To address the observed problems, the study's authors recommended moving from the existing spot-treatment approach to a systemic safety approach. This would include traffic calming treatments for multi-lane streets with unsignalized pedestrian crosswalks, the addition of medians with pedestrian refuges on two-way two-lane streets, changes in signal timing to reduce vehicle-pedestrian conflicts at signalized intersections, and the addition of mid-block crosswalks or grade separations at currently-untreated sites with high pedestrian demand. In the latter case, the use of the British Pelican or Puffin designs was recommended.

Maxwell et al. (2012) continued the previous British efforts to assess the safety and operational performance of the Puffin crossing design. Their study focused on the effects of having the pedestrian signal lights on the near side of the crossing (Figure 83), in contrast to the far-side pedestrian signals used in the older Pelican design and in North American practice. Specifically, a Puffin was modified by adding far-side pedestrian signal heads, and a four-day trial was conducted to compare pedestrian behavior and pedestrian perceptions under the two configurations. The crossing was located in Edinburgh, Scotland and served about 15 pedestrians per hour.

Pedestrian surveys showed that the standard Puffin crossing (with near-side pedestrian indicator lights) had high approval levels, including a 98% rating for ease of use, 86% for perceived safety, and 83% for user satisfaction. Respondents felt certain about whether it was safe to start crossing (99%) and safe to continue crossing (99%), and low levels of anxiety on the crossing (13%). In contrast, moving the signals to the far side increased perceptions of the delay before the start of the GREEN MAN (walk phase), increased uncertainty about when to start to cross, reduced understanding of the RED MAN and GREEN MAN signals, and reduced the number of pedestrians who strongly agreed that it was easy to see the pedestrian indicators while waiting to cross.

When the far-side modification was in operation, more motorists violated the red light at the end of the pedestrian stage. In addition, pedestrians were less likely to be watching traffic prior to and during crossing. Moreover, the far side signal resulted in a significant increase in pedestrians starting to cross before the start of the GREEN MAN (walk phase). Although pedestrians cannot see near-side signals after they enter the crossing, reviews of the video recordings indicated no difference in the extent to which pedestrians seemed confident they had the right-of-way.

With the standard near-side Puffin, elderly pedestrians and people with disabilities were more certain about when to start crossing, and less likely to feel they had to wait too long for the GREEN MAN to appear. Although elderly pedestrians were more anxious while on the crossing when they could not see the signals, their overall feelings of safety and satisfaction were similar with both designs.

Schroeder et al. (2015) developed guidance for North Carolina DOT and municipalities in North Carolina on when to consider marking pedestrian crosswalks, installing pedestrian signal heads, and providing supplemental crossing treatments. The report features a flowchart intended to make the selection process more systematic. Key inputs include the pedestrian and vehicular volumes, roadway cross section, crossing width, and vehicular speed.

The process unfolds in four stages, referred to as "steps" in the document:

1. Documenting existing characteristics and determining whether the crossing meets MUTCD warrants for a pedestrian signal
2. Unsignalized crossing or midblock crossing assessment
3. Additional/alternative treatments assessment
4. Pedestrian signal assessment

In the first step (Figure 86), evaluators are asked to gather relevant data such as the vehicular and pedestrian volumes, distance to adjacent crossing(s), number of lanes or crossing width, and total pedestrian delay. They check for the presence of an existing or planned ADA-compliant pedestrian path, determine whether the crossing meets the signalization warrants in section 4E.03 of the 2009 MUTCD, and check the pedestrian volume.

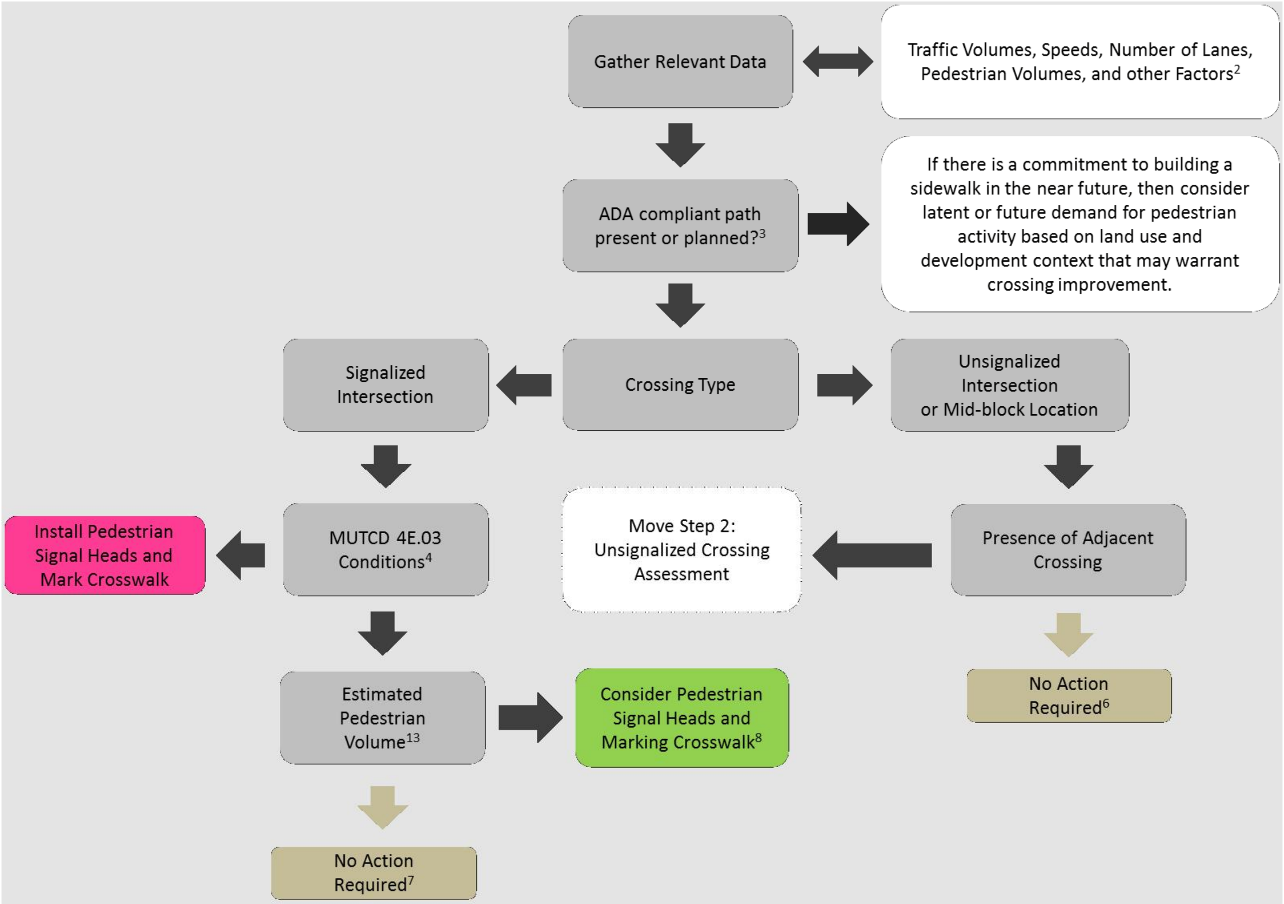

Figure 86. NCDOT Pedestrian crossing treatment flowchart – Step 1

In the second stage, evaluators conduct an unsignalized/mid-block crossing assessment. This includes determining the number of lanes that pedestrians must cross at one time (taking into consideration the median refuge if provided), reviewing the actual speed of motorized traffic, checking the vehicular volume to determine the availability of gaps sufficient for a pedestrian to cross the traffic stream, and checking the pedestrian volume.

The third stage focuses on determining whether the crossing requires geometric improvements, installation of a traffic signal, marking a crosswalk, or other supplemental treatments. The criteria for this process include vehicular speed, peak hour pedestrian volume, MUTCD warrants 4 and 5, and the total pedestrian-hours of delay computed from Equation 18-21 in the 2000 Highway Capacity Manual.

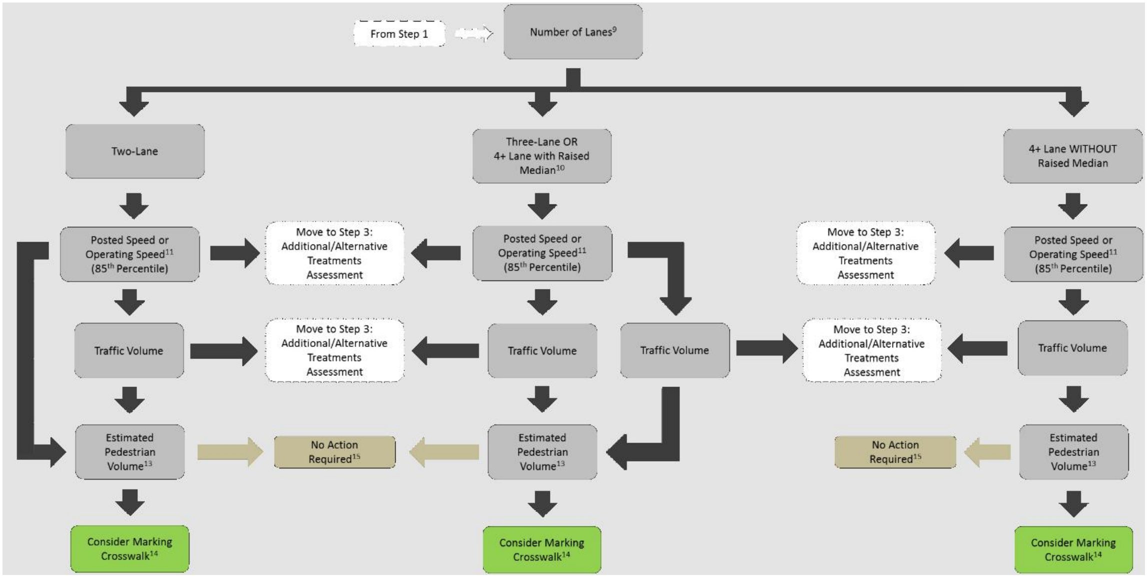

Figure 87. NCDOT Pedestrian crossing treatment flowchart – Step 2

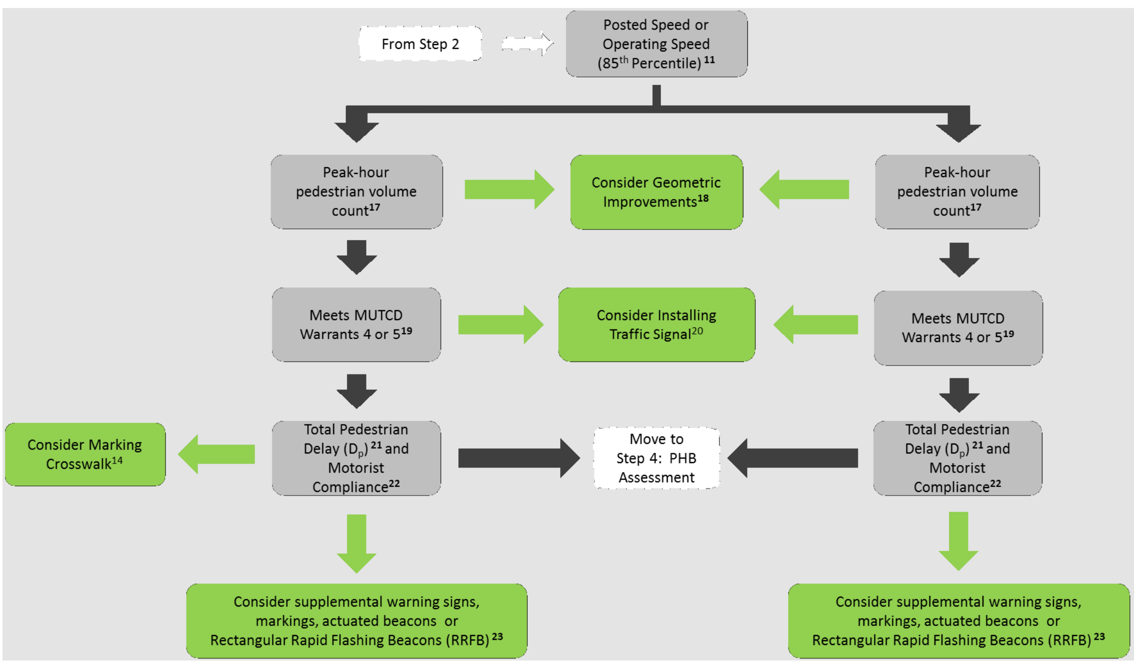

Figure 88. NCDOT Pedestrian crossing treatment flowchart – Step 3

In the fourth stage (Figure 89), evaluators determine whether a pedestrian signal installation should be considered based on the criteria in the 2009 MUTCD (Figure 75 and Figure 76), which are in turn derived from the NCHRP 562 report (Kay Fitzpatrick et al. 2006). This process requires the operating speed, crosswalk length, pedestrian volume, and vehicular volume.

As of April 2022, the entire flowchart was available on the NCDOT website; it is intended for printing as an oversize wall poster (85” x 36”).

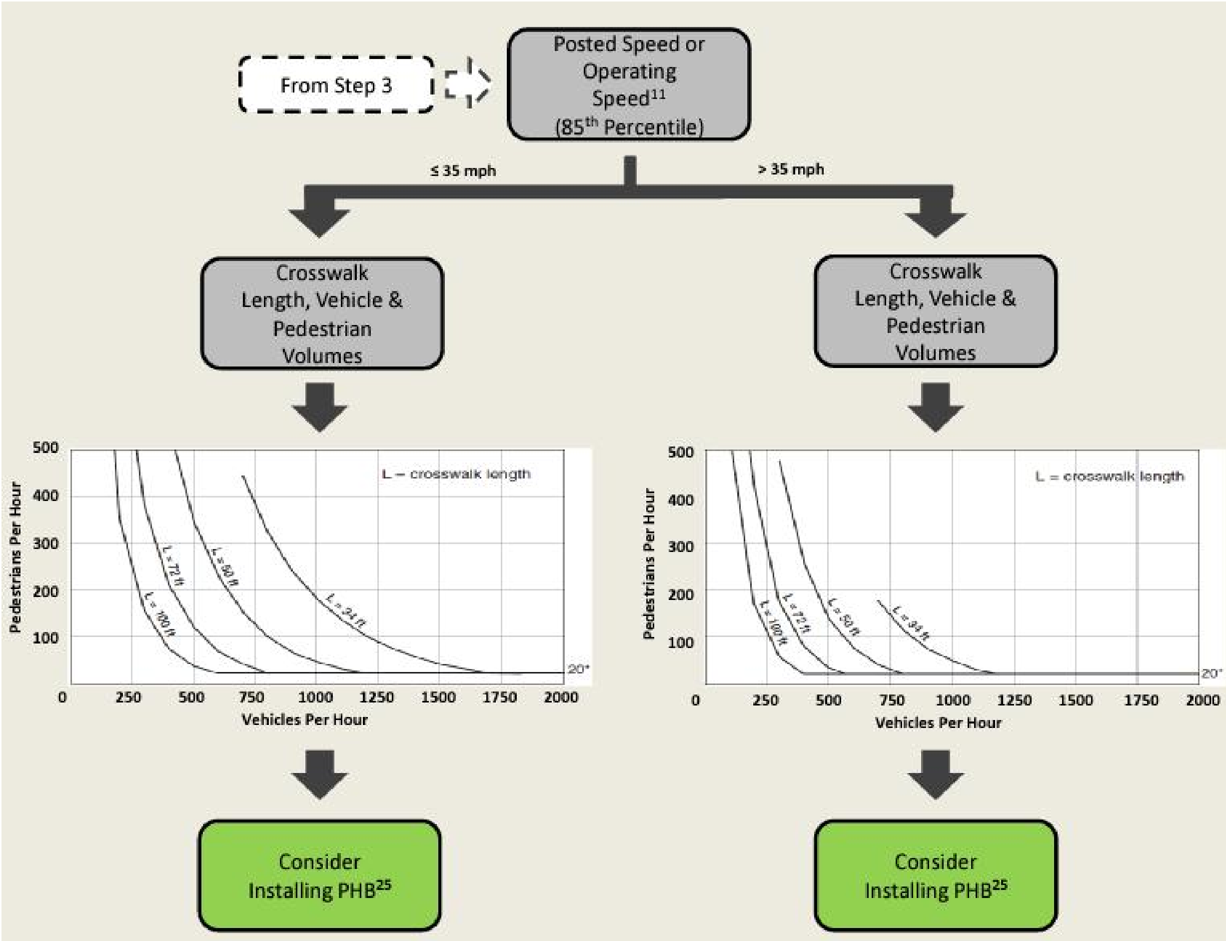

Figure 89. NCDOT Pedestrian crossing treatment flowchart – Step 4

Jain and Rastogi (2017) reported that the PV^2 formulation for pedestrian signalization warrants originally developed in the United Kingdom was subsequently adopted by other jurisdictions, including India and Iran. P represents the pedestrian volume (pedestrians per hour) and V represents the peak hour vehicular volume (vehicles per hour).

As noted earlier, the 1974 the British guidance stated that a pedestrian signal was warranted if PV^2 exceeded 100,000,000 for crossings on undivided roadways. Later, a threshold of 200,000,000 was established for crossings on divided roadways (compare Figure 78 and Figure 90). In the mid-1990s, the UK Department for Transport moved away from a strictly volume-based approach, instead recommending a balanced judgment with consideration of not only pedestrian and vehicular volumes, but also factors such as number of lanes, one-way vs two-way traffic flow, lighting, sight distance, presence of bus stops, prior crash history, and the extent to which the crossing is used by children, the elderly, and people with disabilities. In response, several British municipalities developed their own guidelines using combinations of PV^2 thresholds and more subjective factors.

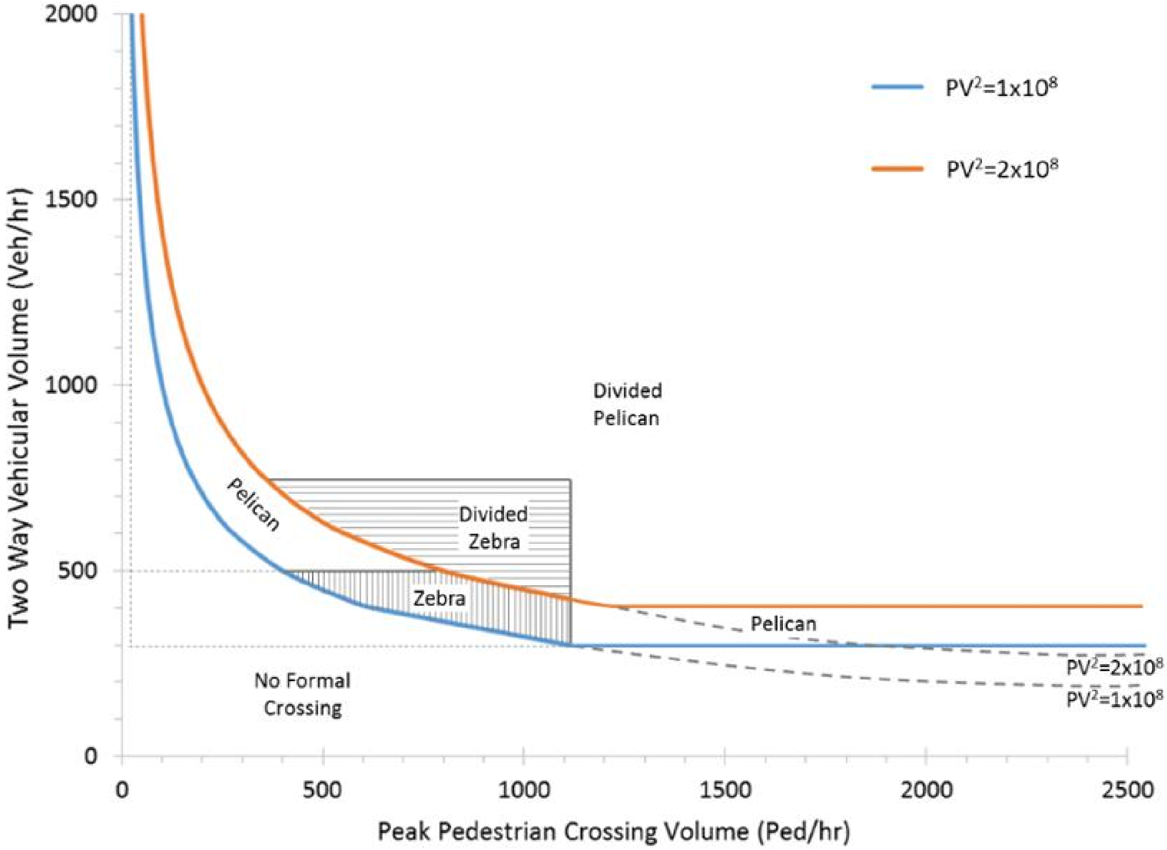

Figure 90. British PV^2 pedestrian signalization guidelines.

Although India initially adopted the 1980s British PV^2 guidance and its thresholds more or less verbatim, Jain and Rastogi felt that by the mid-2010s it was no longer suitable for Indian conditions due to substantial growth in both pedestrian and motor vehicle traffic volumes. A similar conclusion had been reached by agencies in Iran. Jain and Rastogi also reviewed other national guidelines. They felt the 2009 US MUTCD lacked specificity as to the crossing type to be used. Although they concurred with the inclusion of both behavioral and traffic flow considerations in the guidelines for Australia and New Zealand, they felt the Australasian guidance was too data computationally intensive for application in India.

Figure 91. Traffic near Ratan Lal Market, New Delhi, India (November 2015) Source: =UT=/Panoramio

The traffic in Indian cities is a diverse mix of trucks, buses, cars, three-wheel taxis (auto rickshaws), motorcycles, and bicycle rickshaws (Figure 91), often with heavy pedestrian flows. In urban areas vehicles often use the lateral road space fluidly: the traffic does not travel in predefined lanes. Jain and Rastogi collected local traffic data and reformulated the PV^2 thresholds to reflect the effects of these conditions. Based on the data, they proposed specific thresholds for unsignalized, signalized, and grade-separated pedestrian crossings. The resulting PV^2 thresholds are much higher than the original British guidance (Table 28).

Table 28. Warrants for various types of pedestrian crossings (Jain & Rastogi 2017)

	PV^2 Value Ranges*			
Crossing Type	**2-Lane 2-Way**	**3-Lane 2-Way**	**4-Lane 2-Way**	**6-Lane 2-Way**
No Facility	$< 4.2 \times 10^8$	$< 8.5 \times 10^8$	$< 2.5 \times 10^9$	$< 5.6 \times 10^9$
Zebra Crossing (unsignalized)	4.2×10^8 - 3.0×10^9	8.5×10^8 - 6.5×10^9	2.5×10^9 - 2.05×10^{10}	5.6×10^9 - 4.8×10^{10}
Pedestrian Signal	3.0×10^9 - 2.1×10^{10}	6.5×10^9 - 4.9×10^{10}	2.05×10^{10} - 1.6×10^{11}	4.8×10^{10} - 4.1×10^{11}
Grade Separated	$> 2.1 \times 10^{10}$	$> 4.9 \times 10^{10}$	$> 1.6 \times 10^{11}$	$> 4.1 \times 10^{11}$

*Where P is the Peak Hour Pedestrian Flow and V is the Peak Hour Vehicle Flow of both directions

Ontario Ministry of Transportation established guidance for the selection of the most appropriate type of pedestrian crossing treatment based on site conditions in Volumes 12 and 15 of the Ontario Traffic Manual (MTO 2012, 2016). The guidance sets up a hierarchy of treatments intended to reflect the complexity of the conditions at each location. It includes decision support tools to assist practitioners with assessing pedestrian crossing needs and selecting an appropriate treatment system.

In contrast to US states, Canadian provinces have wide leeway to set their own standards for traffic control devices. Inter-provincial coordination occurs primarily through the Transportation Association of Canada (TAC), rather than through the federal government. The Ontario guidance appears to be consistent with model guidelines published by TAC, but uses slightly different terminology, namely the term pedestrian cross*over* instead of cross*walk*.

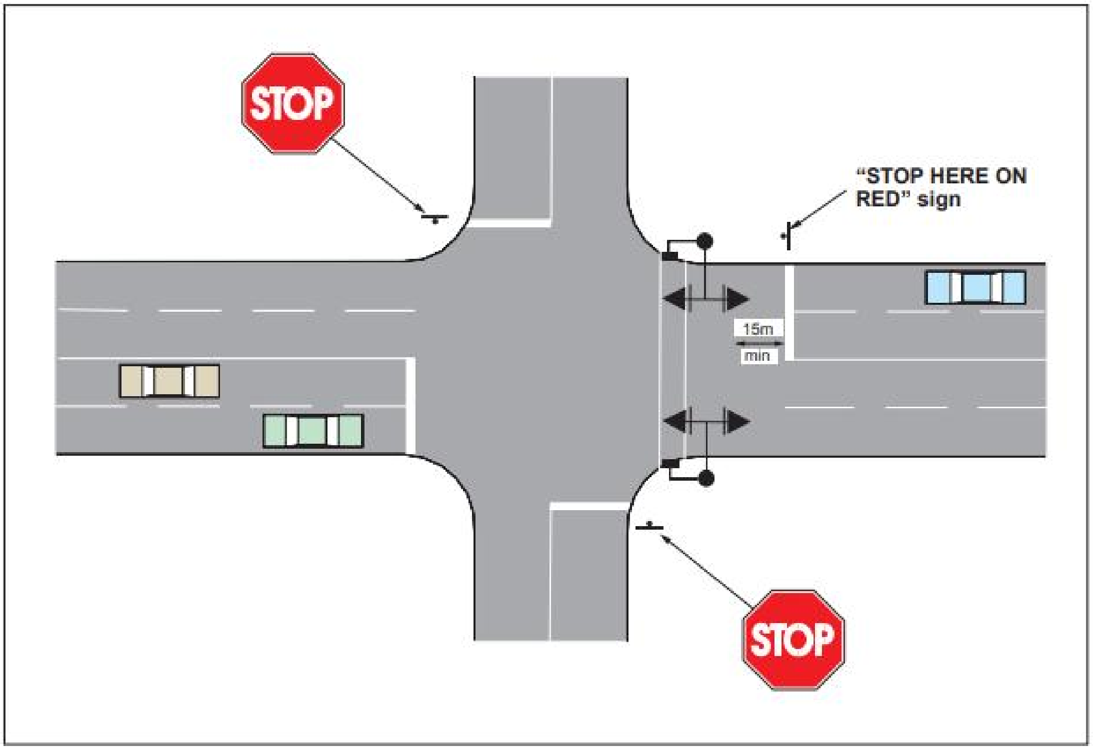

Figure 92. Ontario Intersection Pedestrian Signals (IPS)

The Ontario guidance covers both intersection and mid-block applications, including augmentation of pedestrian crosswalks at roundabouts. Although the guidance does not mention pedestrian signals, it defines three types of signalized junctions where motorists are required to stop:

- Full traffic signals
- Intersection pedestrian signals (IPS, Figure 92) are used at sites "that have considerable pedestrian volumes, but very light traffic on the side road." Typical three-section signal heads are used for the main road, while the side road is stop controlled. Pedestrian signals with pushbuttons are provided for the crossing.
- Mid-block pedestrian signals (MPS) are used at sites that meet the warrants identified in the Canadian MUTCD published by TAC (included in Volume 12 of the Ontario Traffic Manual).

Figure 93. Level 1 Type A pedestrian crossover. Source: City of Toronto

In addition, Ontario defines four types of Pedestrian Crossovers (PXO) where motorists are warned of pedestrian presence. All types include signs and pavement markings, and all except Type D include some form of amber warning beacon:

- Level 1 Type A PXOs (Figure 93 and Figure 94) have pedestrian-actuated circular warning lamps mounted overhead on mast arms, gantries, or span wire, in combination with an internally-illuminated overhead pedestrian crosswalk “X” sign, regulatory signs, and pavement markings.
- Level 2 Type B PXOs (Figure 95) include post-mounted RRFBs, overhead pedestrian crossing signs, both side-mounted and overhead regulatory signs, and pavement markings.
- Level 2 Type C PXOs (Figure 96) have post-mounted RRFBs, side mounted regulatory signs, and pavement markings, but no overhead devices.
- Level 2 Type D PXOs (Figure 97) use only side mounted regulatory signs and do not include flashing beacons.

By law, PXOs can only be used on roadways with speed limits of 60 km/h (37 mph) or less. In addition, Ontario’s guidance contains the following provisions:

- A PXO can be installed on roadways with a maximum of 4 lanes of two-way traffic or 3 lanes of one-way traffic
- A PXO must not be used where the road volume exceeds 35,000 AADT
- PXOs should not be installed within 200 m of other signal-protected pedestrian crossings

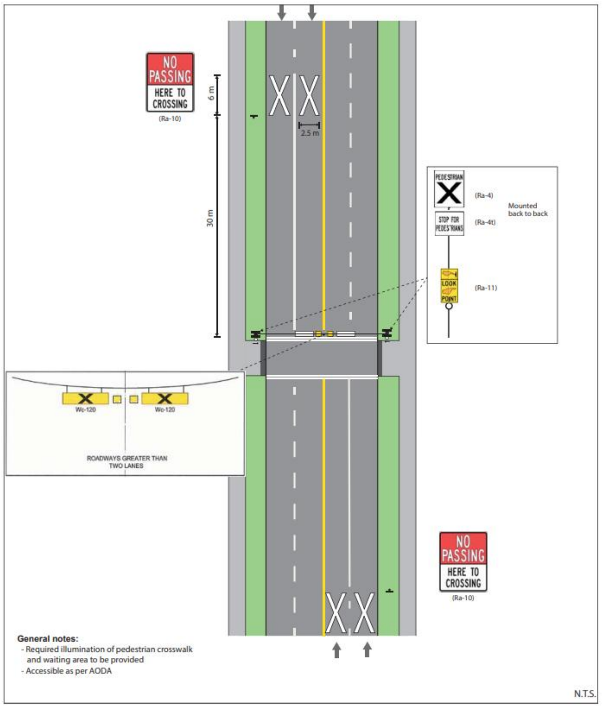

Figure 94. Ontario Level 1 Type A pedestrian crossover (mid-block application)

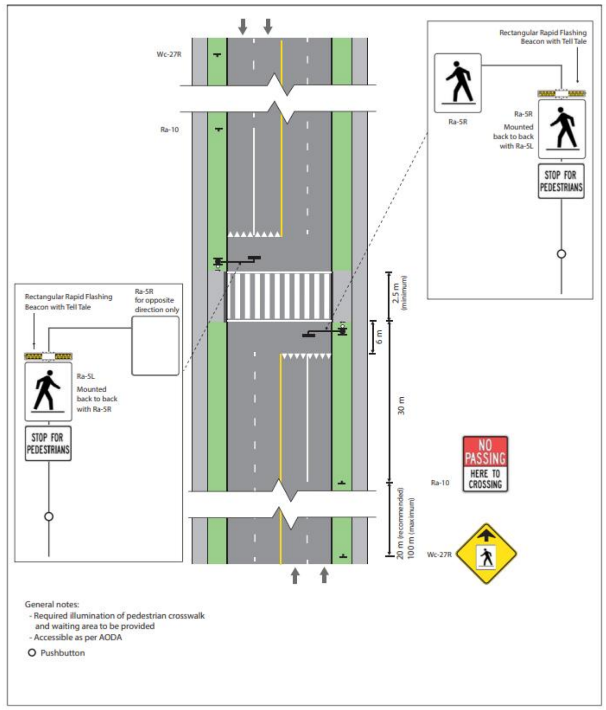

Figure 95. Ontario Level 2 Type B pedestrian crossover (mid-block application)

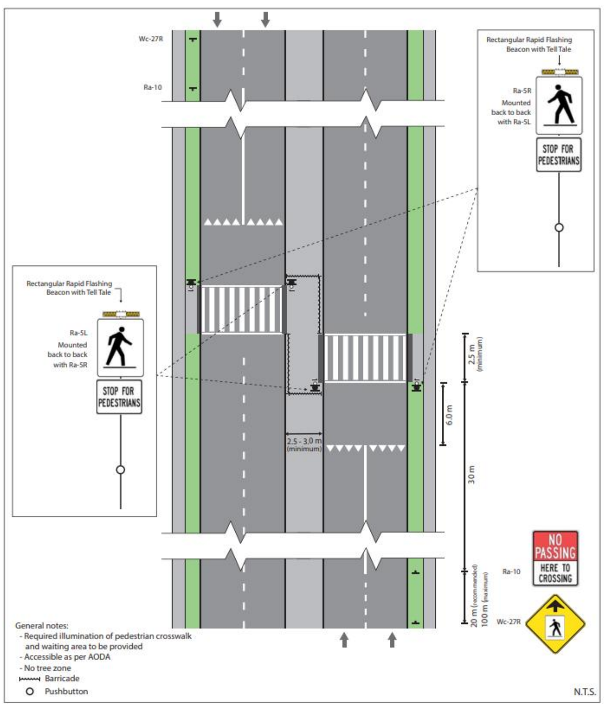

Figure 96 Ontario Level 2 Type C pedestrian crossover (mid-block application with median refuge)

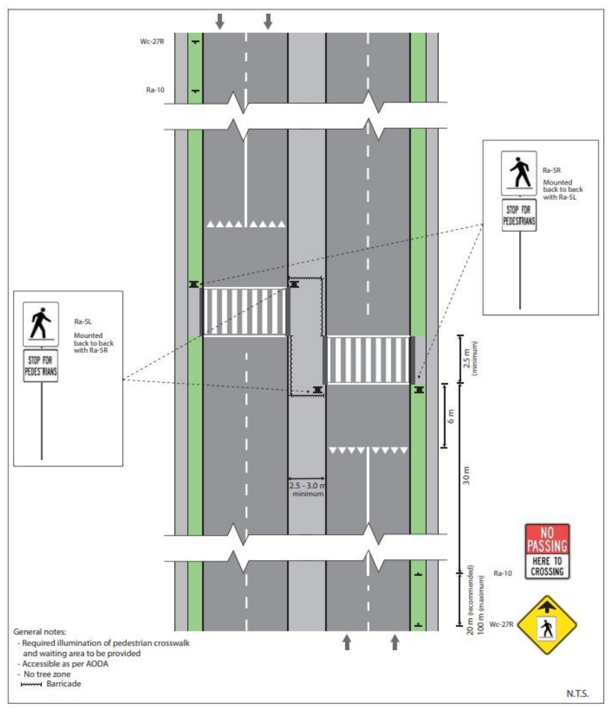

Figure 97. Ontario Level 2 Type D pedestrian crossover (mid-block application with median refuge)

The guidance devotes an entire chapter to the selection of an appropriate crossing system. This begins with a preliminary assessment to determine whether the site has adequate sight distance for a pedestrian crossing and whether it meets warrants for a traffic signal. If a traffic signal is not warranted, a flow chart (Figure 98) assists in determining whether a PXO is warranted.

In the computation of pedestrian volume for the purposes of assessing warrants, Ontario distinguishes between "unassisted" pedestrians (adults and adolescents age 12+) and "assisted" pedestrians (children under the age of 12, seniors, people with disabilities, and other pedestrians requiring special consideration or assistance). Assisted pedestrians count as double:

$$\text{Adjusted Volume} = \text{Unassisted Pedestrian Volume} + 2 \times \text{Assisted Pedestrian Volume}$$

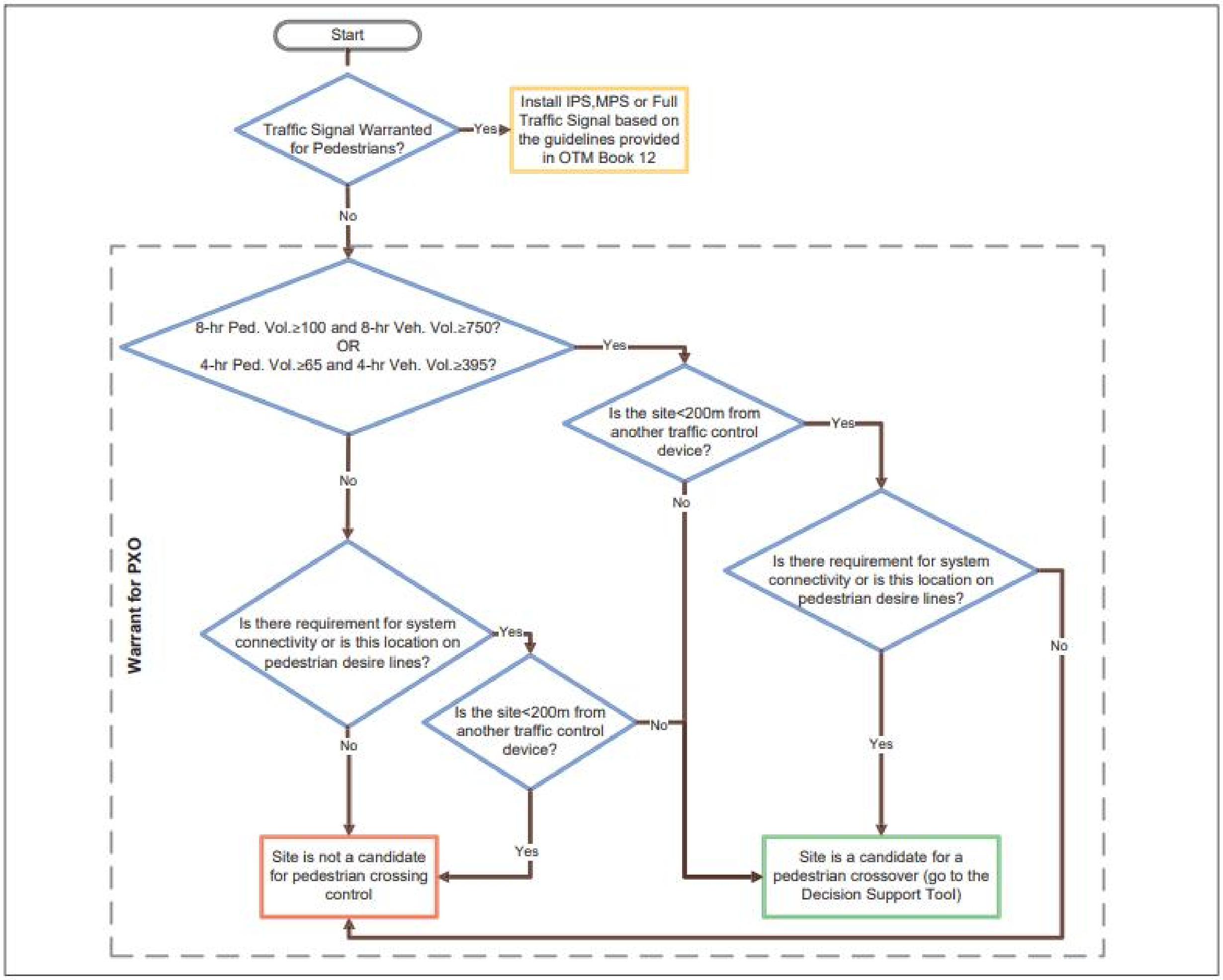

Figure 98. Ontario preliminary pedestrian treatment selection flowchart (MTO 2016)

Threshold values for Ontario's PXO warrants are based on traffic volume, crossing distance, and pedestrian system connectivity. The thresholds are derived from research by Zegeer and are based mainly on combinations of the 8-hour pedestrian and vehicular traffic flows and delays, with an alternative of using 4-hour flows and delays (mainly in small communities) (Figure 99 to Figure 102). Vehicular traffic volumes are collected during the 8 or 4 hours with the highest pedestrian volumes.

If the minimum pedestrian and vehicular volume requirements are not met, a PXO could still be warranted based on system connectivity considerations. The analyst is asked to use judgment to identify pedestrian desire lines and determine whether pedestrians would need to walk more than

200 meters (660 feet) to reach the nearest traffic control device (such as a signalized intersection). The threshold of 200 meters was set "to avoid proliferation of traffic control devices in close proximity of each other."

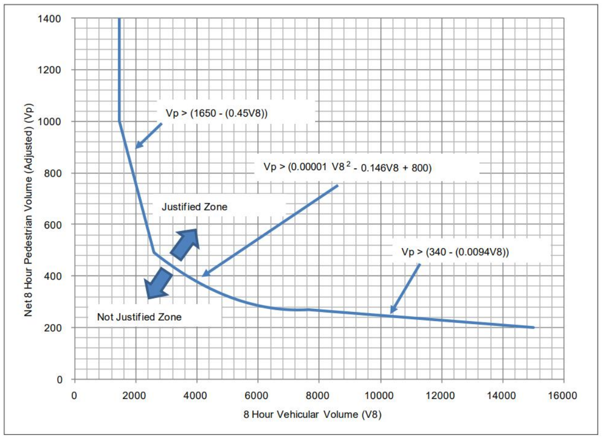

Figure 99. Ontario PXO warrants based on 8-hour traffic volumes

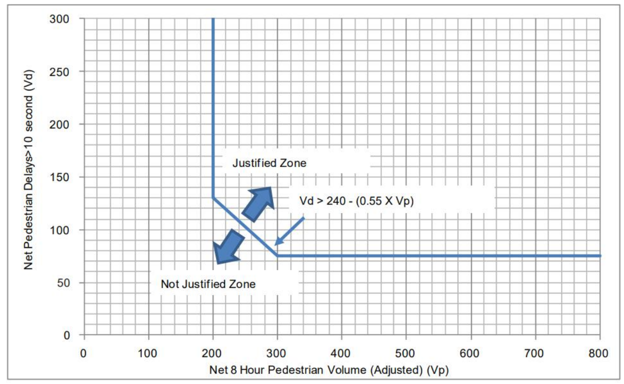

Figure 100. Ontario PXO warrants based on 8-hour pedestrian delays

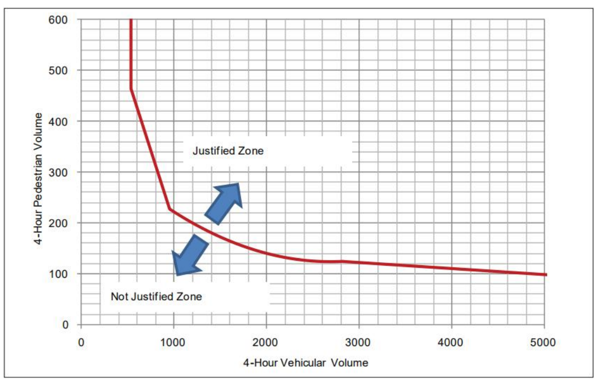

Figure 101. Alternative Ontario PXO warrants based on 4-hour volumes

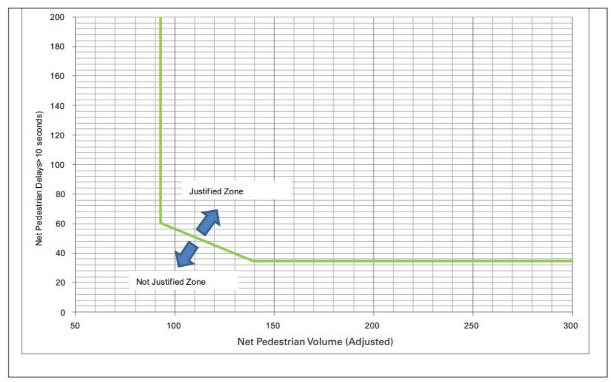

Figure 102. Alternative Ontario PXO warrants based on 4-hour pedestrian delays

As shown in Table 29, the selection of a specific type of PXO is based on vehicular volume, traffic speed, number of lanes, and the presence or absence of a median refuge. PXOs are not used where the speed limit exceeds 60 km/h (37 mph), nor where the annual average daily traffic volume (AADT) exceeds 35,000. The Ontario guidance notes that generally a traffic signal is warranted under the latter two conditions.

Table 29. Ontario pedestrian treatment selection criteria (MTO 2016)

Two-way Vehicular Volume			Posted Speed Limit (km/h	Total Number of Lanes for the Roadway Cross Section[1]			
Time Period	Lower Bound	Upper Bound		1 or 2 Lanes	3 lanes	4 lanes w/raised refuge	4 lanes w/o raised refuge
8 Hour	750	2,250	≤50	Level 2 Type D	Level 2 Type C[3]	Level 2 Type D[2]	Level 2 Type B
4 Hour	395	1,185					
8 Hour	750	2,250	60	Level 2 Type C	Level 2 Type B	Level 2 Type C[2]	Level 2 Type B
4 Hour	395	1,185					
8 Hour	2,250	4,500	≤50	Level 2 Type D	Level 2 Type B	Level 2 Type D[2]	Level 2 Type B
4 Hour	1,185	2,370					
8 Hour	2,250	4,500	60	Level 2 Type C	Level 2 Type B	Level 2 Type C[2]	Level 2 Type B
4 Hour	1,185	2,370					
8 Hour	4,500	6,000	≤50	Level 2 Type C	Level 2 Type B	Level 2 Type C[2]	Level 2 Type B
4 Hour	2,370	3,155					
8 Hour	4,500	6,000	60	Level 2 Type B	Level 2 Type B	Level 2 Type C[2]	Level 2 Type B
4 Hour	2,370	3,155					
8 Hour	6,000	7,500	≤50	Level 2 Type B	Level 2 Type B	Level 2 Type C[2]	Level 1 Type A
4 Hour	3,155	3,950					
8 Hour	6,000	7,500	60	Level 2 Type B	Level 2 Type B		
4 Hour	3,155	3,950					
8 Hour	7,500	17,500	≤50	Level 2 Type B	Level 2 Type B		
4 Hour	3,950	9,215					
8 Hour	7,500	17,500	60	Level 2 Type B			
4 Hour	3,950	9,215					

Type A Type B Type C Type D

Approaches to roundabouts should be considered a separate roadways.

[1]The total number of lanes is representative of crossing distance. The width of these lanes is assumed to be between 3.0 m and 3.75 m according to MTO Geometric Design Standards for Ontario Highways (Chapter D.2). A cross sectional feature (e.g. bike lane or on-street parking) may extend the average crossing distance beyond this range of lane widths.

[2]Use of two sets of side mounted signs for each direction (one on the right side and one on the median)

[3]Use Level 2 Type B PXO up to 3 lanes total cross section one-way.

The hatched cells in this table show that a PXO is not recommended for sites with these traffic and geometric conditions. Generally a traffic signal is warranted for such conditions.

Zhao, Ma, and Li (2017) noted that most of the previous research on mid-block pedestrian crossings has focused either on identifying locations with high pedestrian demand, or on signal timing optimization given a predetermined crosswalk location. They suggested that within some range, the location of the pedestrian crossing can be adjusted to minimize its impacts on the combined vehicular and pedestrian delays. They argued the delay computations should include both turning vehicles and through movements (some procedures ignore delays to turning vehicles).

Zhao, Ma, and Li recommended a signal timing strategy that allows pedestrians at the mid-block crossing to utilize the vehicular red time at the downstream intersection, and adjusts the crosswalk location to optimize signal coordination along the corridor. Consequently, their optimization model combines location selection and signal timing in a unified framework.

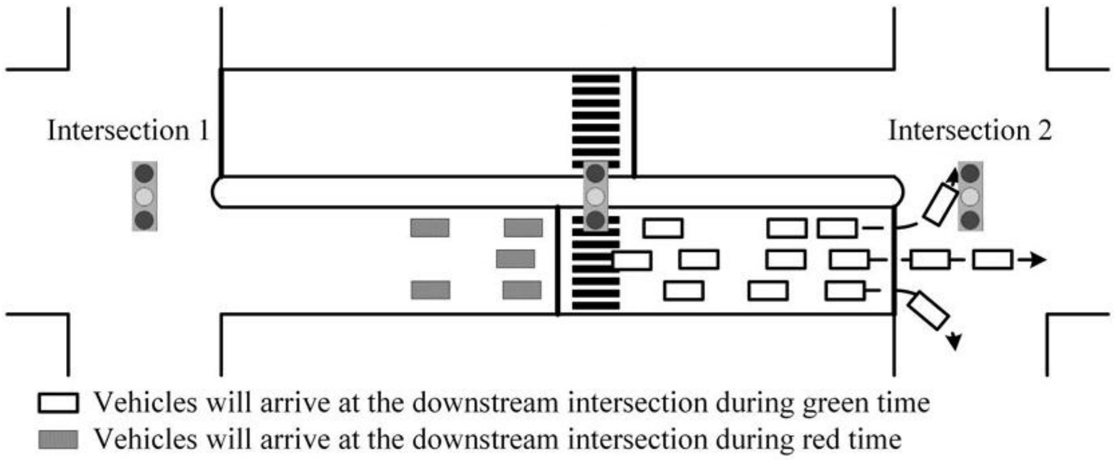

Figure 103. Relationship between crossing location and timing strategy used by Zhao, Ma and Li (2017).

As shown in Figure 103, Zhao, Ma, and Li observed that even under good signal coordination, some approaching vehicles will fail to reach an intersection while the signal is green. Interrupting these vehicles at a crosswalk upstream of the intersection will not have much effect on their travel time, if the pedestrian interval at the upstream mid-block crossing runs concurrently with the red phase of the downstream signal.

Mathematically, they sought to maximize the weighted average bandwidth between the crosswalk and the downstream intersection (including the left turn, through movement, and right turn vehicles in both directions of the road), while simultaneously maximizing the weighted average bandwidth of pedestrians at the crosswalk in both directions. As further constraints, they assumed the crosswalks should be located no more than 60 to 90 meters (200 to 300 feet) apart in high pedestrian volume locations, the crosswalk location could not be moved more than 50 meters (160 feet), the number of pedestrians on the median refuge should be limited based on its physical size, and the queue of vehicles approaching at the mid-block crossing should not be allowed to spill back into the upstream intersection.

Using a busy arterial in Zhangjiagang, China as a case study, they found the optimal location for the crossing is not necessarily the midpoint between the signals. When the crossing was optimally located, the additional vehicular delay was very small (less than 2 seconds for the through movements). The overall system performance (weighted vehicular and pedestrian delay) deteriorated as the crossing location moved away from the optimal location, with a decrease of approximately 1.2% in bandwidth for every 10 meter (33 foot) increase in the difference between the actual crosswalk location and the optimal one.

Two-stage pedestrian crossings always outperformed single-stage crossings in the delay analysis. If the pedestrian delay is ignored, a two-stage design can be optimized for vehicular timing regardless of where the crosswalk is located, but this is not the case with a one-stage design.

Blackburn, Zegeer, and Brookshire (2018) developed an FHWA guide for the screening and selection of pedestrian safety improvements. Based on Zegeer (2005), the guide notes that for multi-lane roadway crossings with vehicle AADTs exceeding 10,000, a marked crosswalk alone is typically insufficient. Under such conditions, more substantial crossing improvements (such as the refuge island, pedestrian signal, and RRFB) are also needed to prevent an increase in pedestrian crash potential.

In addition to the information reproduced in Table 23 (Page 93) and Table 24 (Page 94), the guide offers the following treatment selection advice:

- RRFBs are particularly effective at multilane crossings with speed limits less than 40 mph. Consider the pedestrian signal instead of RRFBs for roadways with higher speeds.
- Pedestrian signals are most effective at roads with three or more lanes that have AADTs above 9,000. Pedestrian signals should be strongly considered for all midblock crossings where the roadway speed limits are equal to or greater than 40 mph. They should be located at least 100 feet away from a signalized intersection.

The guide also discusses passive treatments such as in-street pedestrian crossing signs, stop line markings, curb extensions, raised crosswalks, pedestrian refuge islands, and road diets, but does not address grade separation.

Pulugurtha, Kukkapalli, and Mane (2018) used empirical Bayesian (EB) analysis to compare the motor vehicle crash rates within a ¼ mile buffer of 13 pedestrian signals in Charlotte, North Carolina with the expected crash performance in the absence of a pedestrian signal. Three years of data from a total of 59 unsignalized mid-block crosswalks in Charlotte were used as controls. Pedestrian crashes were not examined, since only two pedestrian crashes occurred amongst the 13 sites before the pedestrian signal installation and only one after installation, and because pedestrian counts were not available.

The analysis found that compared to the expected number of crashes predicted by the EB analysis, motor vehicle crashes increased after pedestrian signal installation at 5 of the 13 sites. Amongst these 5 sites, four did not have a median, two had center left-turn lanes, two were on two-lane roadways, and two had high traffic volumes. Mathematical modeling indicated that traffic volume, speed limit, and road width were positively correlated to the number of all crashes. Land use characteristics such as office, multi-family, retail, and vertical mixed land use were also positively correlated to the number of all crashes; conversely single-family detached housing was negatively correlated to the number of all crashes. Demographic

variables such as household size, income, and the race/ethnicity of people living in the adjoining census tracts were not correlated to the number of all crashes.

Based on these results, the authors cautioned that installing pedestrian signals at mid-block locations along high traffic volume, high-speed and wide roads, and at locations near office, multi-family, retail, and vertical mixed land use areas could lead to an increase in the total number of crashes near the pedestrian signal. The authors noted that confidence in the results is limited by the small sample size.

Chamberlin et al. (2019) developed guidance for Utah pedestrian crossing safety treatments within Reduced-Speed School Zones (RSSZs) where there is significant pedestrian crossing demand outside of the normal school crossing hours. They described this situation as occurring when a school or a building adjacent to the school is an activity center outside of normal school crossing times, such as a place for civic meetings or for general civic gatherings or recreation.

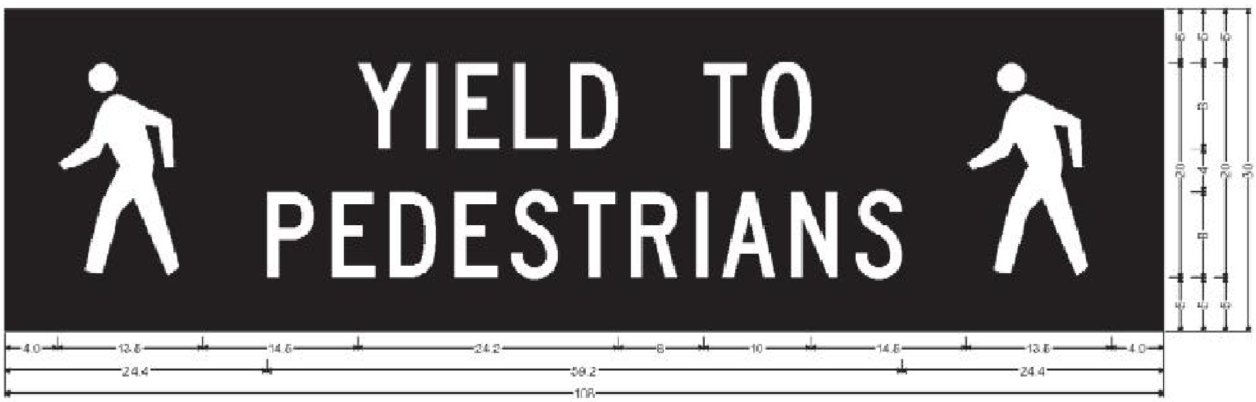

Figure 104. Blank-out sign augmenting school pedestrian crossings as part of the Utah Overhead School Pedestrian Assembly (OSPA).

One item of particular interest was the Overhead School Pedestrian Assembly (OSPA) described in the 2009 Utah MUTCD. This state-specific traffic control device is essentially a pedestrian-activated blank-out sign with the words YIELD TO PEDESTRIANS and two walking-person icons (Figure 104). The 2009 Utah MUTCD required this device to be interlocked with any school speed limit assembly, so that the two devices would not be operated concurrently. Chamberlin et al felt this restriction was unnecessary, but there was limited operational evidence because only two sites were equipped with OSPAs at the time of the study.

Chamberlin et al conducted interviews in an attempt to identify how other jurisdictions determine which types of supplemental traffic control devices to use at school crossings. In general, they found the decisions were *ad hoc,* with few documented criteria. In some states there were legal or policy constraints on using RRFBs or pedestrian signals in combination with other school-related pedestrian traffic controls, but the rationales for these prohibitions were opaque. Only Illinois and Wyoming had policies specifically allowing or alluding to the use of RRFBs in school zones, but the pedestrian volumes in Wyoming were generally too low to justify the use of an RRFB solely on the basis of pedestrian traffic, and the Illinois policy mentioning the use of RRFBs and pedestrian signals in school zones was still in draft form. Some of the practitioners participating in the interviews felt evaluations of the need for enhanced pedestrian treatments near schools should be integrated with overall pedestrian traffic safety efforts, while others thought school-related pedestrian traffic and general pedestrian traffic should be evaluated separately.

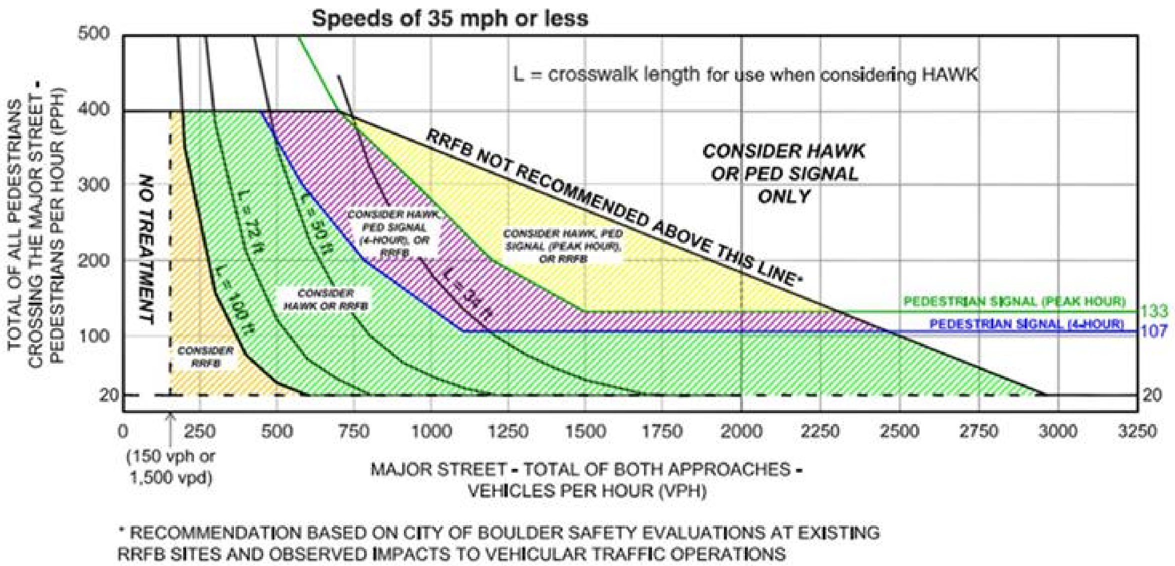

Figure 105. City of Boulder guidelines for the installation of RRFB, pedestrian signal, and pedestrian signals on low-speed roadways (Chamberlin et al. 2019).

Chamberlin et all reproduced a chart prepared by the City of Boulder, Colorado (apparently based on Kay Fitzpatrick et al. (2006)) that provides specific criteria for the use of RRFBs, pedestrian signals , and mid-block signals based on hourly pedestrian and motor vehicle volumes and crosswalk length (Figure 105). They also prepared a chart (apparently based on Blackburn, Zegeer, and Brookshire (2018)) suggesting selection criteria based on AADT, traffic speed, number of lanes, and presence or absence of a raised median (Table 30). The chart does not include criteria for the RRFB vs pedestrian signal decision.

Table 30. Recommended guidance for the installation of pedestrian crossing enhancements within reduced-speed school zones (Chamberlin et al 2019).

ROADWAY TYPE (number of lanes and median type)	ADT < 9,000			ADT 9,000 TO 12,000			ADT 12,000 TO 15,000			ADT > 15,000		
	≤ 30 MPH	35 MPH	≥ 40-45 MPH	≤ 30 MPH	35 MPH	≥ 40-45 MPH	≤ 30 MPH	35 MPH	≥ 40-45 MPH	≤ 30 MPH	35 MPH	≥ 40-45 MPH
Two Lanes	1	1 and/or 2	2 or 4	1	1 and/or 2	2 or 4	2	2	2 or 4	2 or 3 or 4	2 or 3 or 4	2 or 3 or 4
Three Lanes with Raised Median	1	1 and/or 2	2 or 4	1 and/or 2	2 or 4	2 or 4	2 or 4	2 or 4	2 or 4	2 or 3 or 4	2 or 3 or 4	2 or 3 or 4
Three Lane without Raised Median	1 and/or 2	2 or 4	2 or 4	1 and/or 2	2 or 4	2 or 4	2 or 4	2 or 4	2 or 4	2 or 3 or 4	2 or 3 or 4	2 or 3 or 4
>=Four Lanes with Raised Median	1 and/or 2	2 or 4	2 or 4	1 and/or 2	2 or 4	2 or 4	2 or 4	2 or 4	2 or 4	2 or 3 or 4	2 or 3 or 4	2 or 3 or 4
>=Four Lanes without Raised Median	1 and/or 2	2 or 4	2 or 4	1 and/or 2	2 or 4	2 or 4	2 or 4	2 or 4	2 or 4	2 or 3 or 4	2 or 3 or 4	2 or 3 or 4

1 = Low-Level Treatments (Refer to UDOT Policy 06C-27 *Low-Level Treatments at Uncontrolled Locations*)
2 = Rapid Rectangular Flashing Beacon (RRFB)[2,3]
3 = RRFB and Advance RRFB[2,3]
4 = Pedestrian Activated Overhead School Pedestrian Assembly (RS1-9B)[4]

[1]For application at crosswalks with significant pedestrian crossing demand outside school crossing hours.
[2]Overhead mounting of RRFBs should be considered based on engineering judgment, including the adequacy of visibility achievable by roadside signs
[3]If a median is present, provide an RRFB on the median instead of left of the crosswalk
[4]Additional or different treatments will be required at speeds greater than 45mph
[5]Interlocking of recommended pedestrian crossing treatments with RSSZ devices, making one or the other device non-activatable, is ***not*** recommended.

DeLorenzo et al. (2019) reviewed the current status of pedestrian signal deployments in the United States, focusing on concerns about state laws that require drivers to stop at dark signals. They noted that the intent of such laws is to provide an alternative method of traffic control in case of a signal outage. They also noted that pedestrian signals are not the only type of signal that is ordinarily dark: the same situation occurs at ramp meters and bascule bridges [as well as railroad crossings and various types of warning beacons].

Based on a review of state laws, DeLorenzo et al found that 39 states have laws on dark signals, with 34 requiring drivers to stop completely and five requiring drivers to approach cautiously and yield to pedestrians and vehicles already in the intersection. In general, states that require drivers to stop also stipulate that the dark signal is to be treated as an all-way stop. In contrast, three states (Idaho, Indiana, and Rhode Island) had statutory language specifically addressing pedestrian signals as of the time the report was prepared.

Based on practitioner interviews, 41 states were found to be using pedestrian signals, while 7 allowed pedestrian signals but had not installed any. Among the latter, four states were planning to install one or more pedestrian signals (or were in the process of installing them). The remaining three had no plans to install pedestrian signals.

Some practitioners reported driver confusion related to specific aspects of pedestrian signal operation. For example, a Pennsylvania respondent felt drivers did not clearly understand what to do during the flashing red interval. In 2017 the City of Boulder, Colorado replaced a pedestrian signal with a conventional signal due to driver confusion. A respondent indicated Kentucky was reluctant to deploy pedestrian signals due to perceptions that more driver and pedestrian education would be required.

Fitzpatrick et al (2019) conducted an evaluation of pedestrian signals in Arizona. The study focused mainly on the safety performance of pedestrian signals. Video data collected at 10 locations indicated that overall, 90% of motorists stopped during the steady red phase and 97% of motorists yielded the right-of-way when pedestrians were present at the pedestrian signal. During the flashing red indication about 41% of motorists stopped, with most of the remainder making rolling stops or slowly approaching the back of queue. An empirical Bayesian analysis of Arizona crash data found an overall 18% reduction in crashes at pedestrian signals, relative to a control group of signalized and unsignalized intersections. Since crash history was factor in selecting the pedestrian signal locations, this value could decline as pedestrian signals become more widely used.

Arizona DOT's existing procedure for selecting pedestrian signal locations was a point system based on procedures developed by the cities of Tucson and Phoenix. The guidelines recommended against installing pedestrian signals on roadways with speed limits greater than 45 mph, and encouraged a comprehensive review of pedestrian crossing safety to identify the most effective treatment. Volume and speed criteria were MUTCD-based (Figure 75 and Figure 76). Fitzpatrick et al recommended the following changes to Arizona's pedestrian signal site selection criteria:

- Consult the Federal or Arizona Safe Transportation for Every Pedestrian (STEP) guide as a first step in determining whether a location merits further consideration as a pedestrian signal candidate.
- Expand the eligibility to include sites with 50 mph speed limits, based on satisfactory performance of pedestrian signals at such sites in Arizona.
- Collect traffic data during the times of peak pedestrian activity (rather than peak vehicular volume).
- Consider latent pedestrian demand, i.e., pedestrian trips that are currently suppressed due to the difficulty of crossing busy roads.
- Add points to the scoring matrix for speeds of 50 mph, revise AADT levels to be consistent with the FHWA STEP guide, and include guidance for using raised medians.

Fitzpatrick et al also proposed several pedestrian signal design enhancements, such as encouraging the use of two-stage pedestrian signal crossings with staggered entrances where physical space is sufficient (not only for safety, but also to provide more signal timing flexibility). They suggested changes in the pedestrian signal timing plans such as the addition of an all-red clearance interval prior to the start of the walk interval, recommended developing criteria on when to synchronize the pedestrian signals with the corridor signal system, and suggested applying guidance in the 2013 ITE Traffic Control Devices Handbook to develop a pedestrian signal display when an equipment malfunction occurs.

H. D. Golakiya, Patkar, and Dhamaniya (2019) used a combination of field data collection and data modeling to estimate the effect of pedestrians crossing streets on motor vehicle capacity for five cities in northern India. While they found no effect for pedestrian cross-flows of less than 200 pedestrians/hour, the capacity reduction reached about 30% with 1500 pedestrians crossing per hour. They proposed PV^2 criteria for four treatments: zebra crossings, zebra crossings with speed tables, signal-controlled mid-block crossings, and grade separations. The thresholds were much lower than the ones suggested by Jain et al, which the Golakiya group felt were too focused on maximizing traffic flow.

Alemdar, Kaya, and Çodur (2020) developed a GIS-based multicriteria decision making framework for determining the optimal locations for signalized pedestrian crossings. They demonstrated the methodology by developing nine scenarios for signalization of pedestrian crossings along a 0.78 km (0.48 mile) segment of Terminal Street, a busy arterial corridor in the city of Erzurum, Turkey.

The selection process combined four analytical tools:

Analytic Hierarchy Process (AHP) was used to establish weighting factors for 11 site selection criteria, which are listed as Group 1 in Table 31..

- GIS analysis was used to identify potential signalized crossing locations based on land use, taking the AHP weightings of the Group 1 criteria into consideration.

Microsimulation with Vissim software was used to evaluate the impacts of changing the crossing locations on traffic performance along the corridor, generating values for the Group 2 metrics shown in Table 31.

- VIKOR, a standard multicriteria computational algorithm, was used to develop overall scores based on the 13 Group 2 criteria. (The name of this acronym is derived from its name in the Serbian language, VIseKriterijuska Optimizacija I Komoromisno Resenje, meaning “Multicriteria Optimization and Compromise Solution.”)

The authors compared 9 crossing location scenarios:

- Scenario 1 represented the base case, with 18 signalized crossings remaining in their existing locations
- Scenarios 2 and 3 were based on the signalized crossing locations that were likely to serve the most pedestrians according to the GIS analysis
- Scenario 4 moved the signalized crossing locations to coincide with bus stops
- Scenario 5 moved the signalized crossing locations to coincide with bus stops and schools
- Scenarios 6-9 provided uniform spacings of 75, 100, 150, and 200 meters, respectively

To determine the effect of signalized crossing locations on traffic, each scenario was modeled with Vissim and the Group 2 metrics were extracted. Based on the VIKOR analysis, the best-performing scenarios were #2 and #7, while #1 (the existing locations) was the worst. Under Scenario 2, the overall pedestrian and vehicular traffic performance for the corridor improved about 50% compared to the existing conditions.

Table 31. Pedestrian crossing evaluation criteria (Alemdar, Kaya, and Çodur (2020)

Evaluation Criteria Group 1	Evaluation Criteria Group 2
Intersections	Vehicle queue length
Taxi and bus stops	Vehicle delay
Railway crossings	Vehicular stopped delay
Area school demand	Number of vehicular stops
Public buildings	Vehicular emissions
Shopping mall	Fuel consumption
Automatic teller machine (ATM)	Vehicular travel time
Residential demand points	Vehicular safety
Gasoline station	Pedestrian stopped delay
Commercial buildings	Pedestrian travel time
Pedestrian demand	Crosswalk usage ratio
	Pedestrian safety
	Distance between pedestrian crossings

Chaudhari et al. (2020) revisited the pedestrian crossing warrants for India, including the PV^2 values proposed by Jain et al. Focusing on congested cities with high pedestrian mode share, the Chaudhari group proposed an approach based on the average pedestrian delay plus a safety margin. Field data were stratified into 9 functional groups based on the number of lanes and land use. For example, on 6 lane divided roads a zebra crossing would be used when the pedestrian delay exceeds 8 seconds, a zebra crossing with a speed table when delay exceeds 40 seconds, a signalized mid-block crosswalk when the delay exceeds 60 seconds, and grade separation when the delay exceeds 100 seconds.

The study noted age and gender differences in the observed pedestrian delays. Men appeared to accept smaller gaps than women, and women experienced considerably longer delays as a result. [Other studies suggest female pedestrians take fewer risks, and experience fewer casualties]. Similar to the Canadian practice, the group suggested developing age and gender based "pedestrian equivalents" to account for these differences.

Hareshkumar Dahyabhai Golakiya and Dhamaniya (2021a, 2021b) conducted a follow-up to their 2019 study of vehicle-pedestrian interactions under the traffic conditions found in cities in India. They collected additional field data and stratified it to compute the delay by vehicle type, finding that motorcycles and other small vehicles experienced smaller delays than large vehicles such as trucks and buses. Using a non-lane-based microsimulation model, they related the delay to the PV^2 parameter and made downward revisions in the proposed warrants for each of the facility types (Figure 106). For example, in the 2019 paper the PV^2 thresholds for grade separations were 132×10^8 (four-lane roadways) and 214×10^8 (six-lane roadways), while in the 2021 paper the threshold was a total delay greater than 1550 seconds and PV^2 greater than 50×10^8. This value is far lower than the 1.6×10^{11} proposed by Jain et al five years earlier.

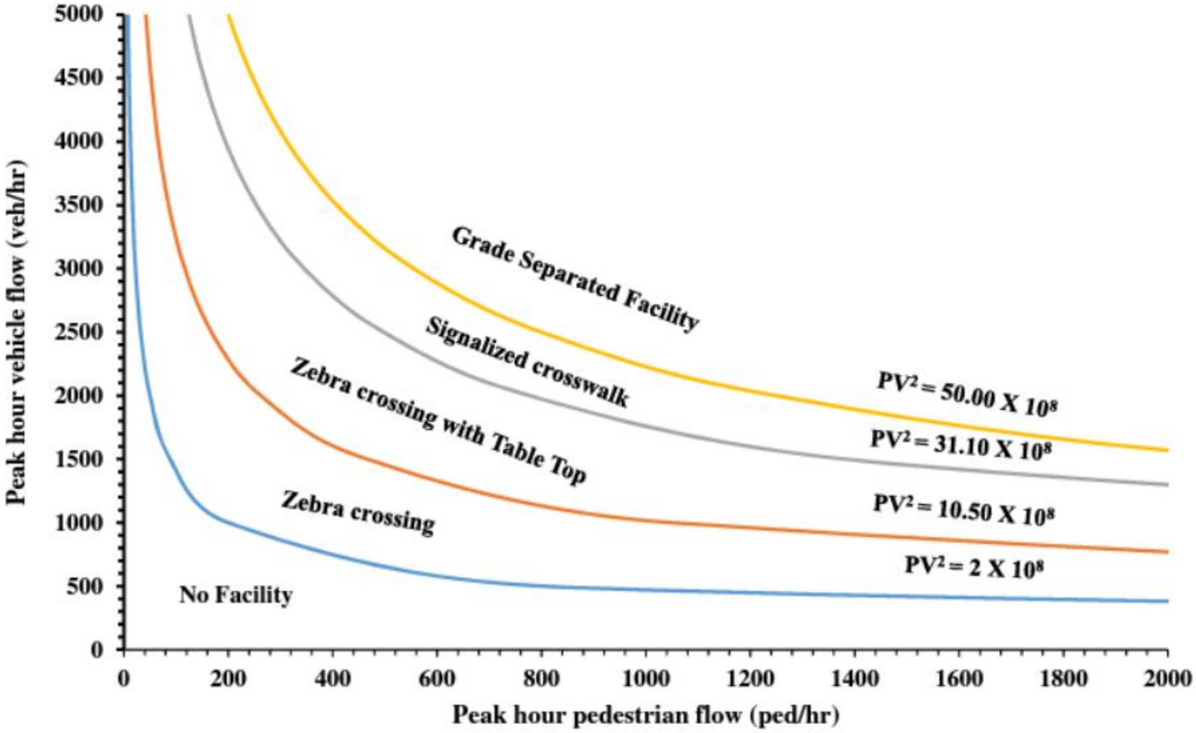

Figure 106. Proposed warrants for pedestrian facilities in India (Golakiya and Dhamaniya 2021).

Summary and Synthesis

The project team completed a comprehensive review of the pedestrian safety treatment selection and site selection literature. Systematic searches of four scholarly databases yielded a total of 167 publications from academic journals and conference proceedings, of which 17 were duplicates. After screening the 150 non-duplicate publications, 29 were found to be relevant to site selection and treatment selection for mid-block pedestrian crossings, and these were augmented with non-academic sources such as national guidelines. Together, these documents provide a record of efforts to define pedestrian crossing treatment selection criteria over the past half-century.

The resulting guidance has ranged from rigid criteria based solely on pedestrian and vehicular volumes, to loose frameworks that ask the analyst to consider a wide range of subjective factors. While volumes are relatively easy to measure, the research suggests road users tend to think about pedestrian crossings in terms of safety, route continuity (ease and directness of access to destinations), and pedestrian comfort (minimization of delays, ease-of-use for people with disabilities, and so forth). Guidance-issuing agencies appear to have struggled to determine how to account for these more subjective factors, particularly in light of differences in site context such as land use, and variations in the age and health of the pedestrians that typically use a specific site.

Selection Process

Taken as a whole, the literature suggests a need for a two-phase site selection and treatment selection approach, specifically a planning phase and a design phase:

- The planning phase involves determining whether existing pedestrian crossings are adequate in terms of location and spacing, including whether there are unmet pedestrian desire lines. Some inadequacies are physically observable in the form of a beaten path, or can be identified from crash records indicating a concentration of pedestrian crashes in a specific area. In other cases the locations where pedestrians cross the roadway are diffused along a broad expanse of roadway frontage; once identified, these trips can potentially be channeled into a finite number of crossings. There are also situations where pedestrian demand has been suppressed by the difficulty of crossing the roadway, or where it is necessary to plan the locations of pedestrian crossings for facilities that do not yet exist.

Mapping of the main pedestrian traffic generators such as bus stops, schools, shopping areas, and major employers has been used to identify these needs. Techniques such as the analytical hierarchy process (AHP) have been used to assist agencies in prioritizing investments in crossing upgrades. It is important to acknowledge the differing priorities of various stakeholder groups such as property developers, pedestrians with disabilities, and the general public. To avoid controversy, agencies must recognize, balance, and reconcile these considerations.

- The design phase involves determining the specific location of the crossing, which treatment to apply, and the details of the treatment. Examples include not only the type of crossing treatment, but also whether median refuges will be provided, and whether the pedestrian crossing device will be coordinated with a corridor signal system.

The most crucial design decision is whether the device will be red or amber, that is to say, whether a pedestrian signal or mid-block signal will be installed to make it mandatory for drivers to stop at the crossing, or whether motorists will simply be advised to yield to pedestrians by deploying some form of amber warning beacon. The literature points toward the need for traffic on high-speed roadways to be brought to a complete stop, with flashing beacons reserved for low-speed facilities where consequences of a fail-to-yield collision are less severe. Flashing amber devices are unlikely to be satisfactory if the AADT exceeds about 10,000 or the traffic speed exceeds 35 to 40 mph. Grade separation should be considered for sites with very high traffic speed, very high pedestrian traffic, or high motor vehicle traffic.

Selection Thresholds

Several sources discuss numerical thresholds for pedestrian safety treatments. Figure 107 and Figure 108 compare the thresholds from the 2009 US MUTCD, the 1980s British guidance for mid-block signals (Pelican/Puffin crossings), and Book 15 of the Ontario (Canada) Traffic Manual. Pedestrian volumes are shown on the horizontal axis and vehicular volumes are on the vertical axis. While the British and US values are specific to signals, the Ontario values include unsignalized crosswalks. The MUTCD and Ontario warrants are based on average volumes over 4 or 8 hours, converted to average hourly flow rates for the purposes of comparison on the charts.

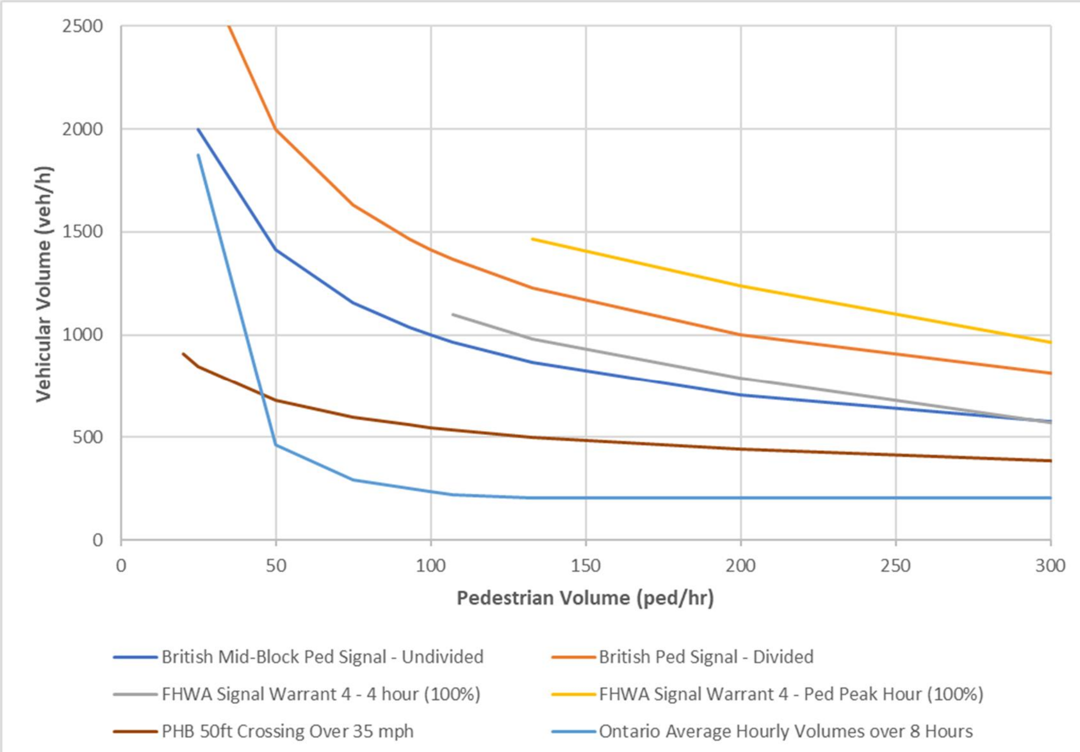

Figure 107. Comparison of American, British, and Canadian thresholds for pedestrian treatments – higher volume/higher speed facilities

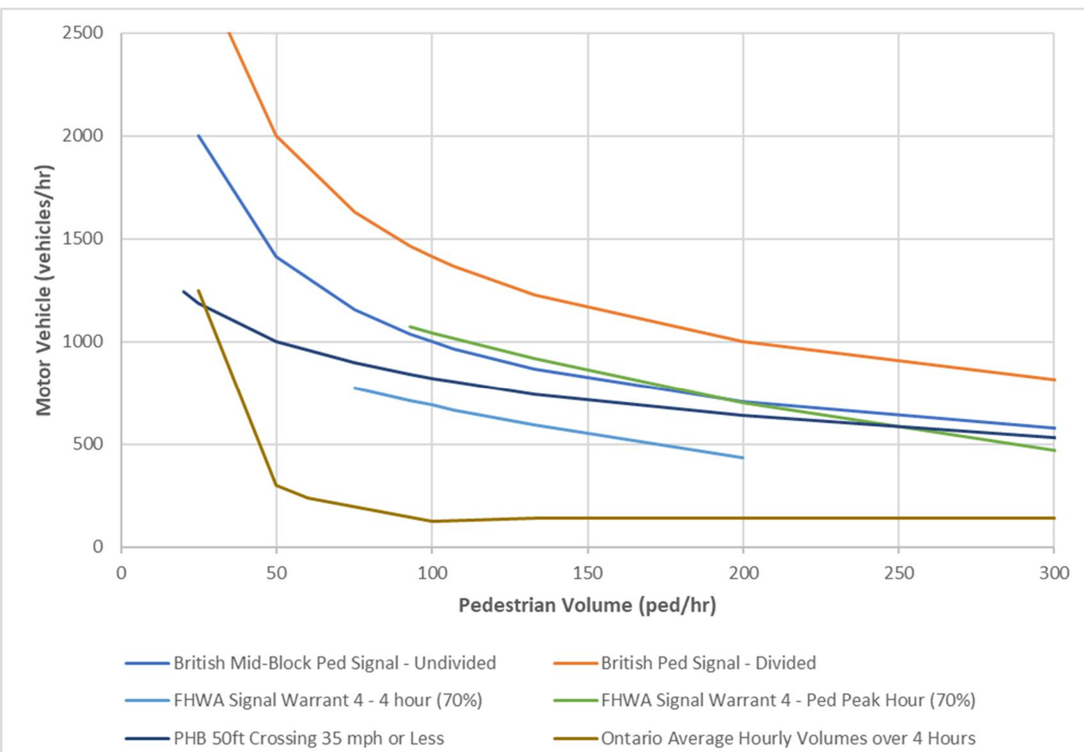

Figure 108. Comparison of American, British and Canadian pedestrian treatment thresholds – lower volume / lower-speed facilities

In many cases the rationales for setting these thresholds do not appear to be well documented. Some have existed for 50 years or more, and appear to have been set to minimize traffic delays or limit the cost of installing and maintaining traffic control devices. This focus on vehicular traffic flow and agency costs contrasts sharply with the current national policy of minimizing fatalities and serious injuries.

Some of the numerical criteria are described as warrants (implying a value above which some action should ordinarily be taken), while others appear to be treated as minimums, i.e., values below which ordinarily no action will be taken. Crossing width is addressed in great detail in some sources, and ignored in others.

Taken as a whole, there appears to be a consensus for a threshold based on a weighted combination of pedestrian and motor vehicle volumes, but as shown in Figure 107 and Figure 108, practitioners appear to disagree on how to set the threshold values. In addition, some guidelines include a second threshold based purely on pedestrian delay.

The curves developed for India and Iran, while numerically unsuitable for US conditions, offer an important conceptual innovation in that they establish a family of parallel threshold curves, each associated with a specific treatment level. This concept could potentially be adapted to set threshold ranges for raised pedestrian crossings, RRFBs, pedestrian signals, and grade separations, and could be augmented with a point system to account for subjective criteria.

The Canadian methodology stands out as having particular clarity in how such a hierarchy could be organized and implemented:

- As volumes grow and operational conditions become more complex, the treatment progresses from a marked crosswalk, to a crosswalk with RRFBs, to a crosswalk with RRFBs and overhead signs, to a crosswalk with overhead signs and large-diameter amber beacons, to a signalized mid-block crossing.
- Although pedestrian signals are not part of this hierarchy, they logically fit between the amber-beacon and signalized-crossing stages. They are particularly suitable for high-speed roadways. Similarly, raised crosswalks potentially occupy a niche between the marked crosswalk and the RRFB.
- While not specifically mentioned in the Canadian guidelines, grade separations (pedestrian overpasses and underpasses) feature prominently in the international research and some of the older American studies. They sit at the top of the hierarchy as the preferred treatment for sites with high traffic speeds or extremely heavy pedestrian or vehicular flows.

The Canadian warrants consider vehicular and pedestrian delays alongside volumes. Highly vulnerable pedestrians (children, elders, and people with disabilities) are doubly-weighted in the volume computations. This avoids the need for a separate analysis of school-related traffic.

Interaction Between Crossing Location and Appropriate Treatment

Another important set of findings from the literature review concerns the interrelationships between a pedestrian crossing's location and design features and its impacts on vehicular traffic delay:

- At each site there is likely to be a crossing location that is optimal in terms of minimizing road user delay. This location is not necessarily the mid-point between signals. Moving an existing closer to optimal location will reduce delays, and moving the crossing away from the optimal location will increase delays.

- For pedestrian safety, the AASHTO Green Book (7th Edition) recommends providing median refuge islands when the crossing distance exceeds 60 feet (18.2 meters). The British guidance is more conservative, stating that designers “should consider” a staggered refuge when the crossing width exceeds 12 meters (39 feet) and “should provide” one when the width exceeds 15 meters (49 feet). The literature review finds evidence that median refuges also directly benefit drivers. By uncoupling the signal timings for the two traffic directions, the presence of a median refuge makes it easier to achieve two-way vehicular traffic progression along a corridor. Ordinarily, this cannot be achieved with single-stage crossings. The use of a two-stage crossing also makes it less critical for the crossing to be in the optimal location.
- For optimal pedestrian safety, the refuge for a mid-block crossing should be fenced, with an offset of at least 10 feet between the entry and exit locations. On two-way streets the offset should be arranged so that pedestrians turn to the right as they enter. This helps assure that pedestrians see the approaching traffic as they exit the offset.

Evidence-Based Treatment Selection

A central quandary presented by the literature is that while treatments such as marked crosswalks, RRFBs, pedestrian signals, mid-block signals, and pedestrian grade separations are implemented primarily as safety treatments, it is difficult to compute pedestrian exposure (and risk) due to the lack of comprehensive pedestrian traffic volume data (i.e., counts of the number of crossing pedestrians). Thus, while the safety benefits of specific treatments can be estimated for reactive deployments at high-crash locations, it has been difficult to establish systemic deployment criteria for pedestrian treatments.

This situation contrasts markedly with the protection of railroad crossings, where automatic equipment can be used to count the daily numbers of trains and motor vehicles. As a result, it is easy to compute daily “exposure” by multiplying the two. For decades, exposure-based selection criteria have been used to define a four-step safety treatment hierarchy: passive crossings with only signage and markings, active crossings with warning lights, gated crossings, and grade separations. Evidence-based selection criteria can then be established for each treatment level. For example, a recent analysis of US railroad crossing crashes showed that relative to a passive crossing, one with flashing lights had 73% less risk per exposure, and a gated crossing had 63% less risk per exposure than a crossing with lights (Brood and Gillen 2020). Such data allows benefit/cost ratios to be computed for railroad crossing safety upgrades, even at sites where no vehicle-train collisions have occurred in the past. It also facilitates rational decisions for the removal of signals or gates at sites where road or rail traffic has declined. If it is possible to extend this computational logic to vehicle-pedestrian crossings, much of the treatment selection ambiguity could be resolved.

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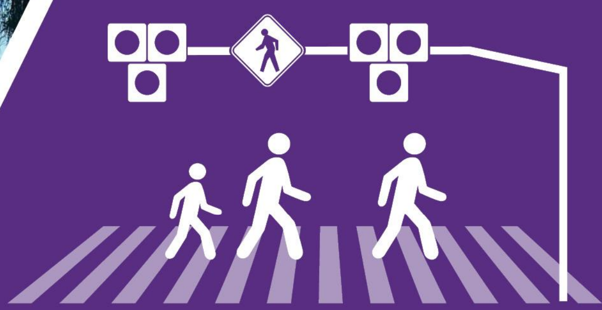
APPENDIX C

STATE OF THE PRACTICE INTERVIEW SUMMARIES

SUMMARY OF INTERVIEWS



Feasibility of Implementing
Pedestrian Hybrid Beacon (PHB) Signals for Improving Safety and Mobility in Nevada

NEVADA DOT SAFE AND CONNECTED

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Institute for Transportation

FEASIBILITY OF IMPLEMENTING PEDESTRIAN HYBRID BEACON SIGNALS FOR IMPROVING SAFETY AND MOBILITY IN NEVADA

SUMMARY OF INTERVIEWS

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OVERVIEW

The purpose of the *Nevada Department of Transportation* (*NDOT) Pedestrian Hybrid Beacon (PHB) Research Project* is to develop device selection criteria and signal timing guidance for corridors with mid-block pedestrian crossings in Nevada. Pedestrians account for nearly 25% of all Nevada traffic fatalities.

This document summarizes interviews completed with various agencies in Nevada as well as throughout the country. Interviews outside of Nevada focus on agencies with existing PHB deployments. It is important to note that PHBs are not widely deployed throughout Nevada at present time. Interview summaries are included in **Attachment A**.

Table 1 – Interviews

Interview Group	Interviewee	Date of Interview
National	City of Austin, TX – Brian Craig	October 22, 2021
National	City of Boca Raton, FL – Maria Tejera	October 25, 2021
National	City of Memphis, TN – Nick Oyler	October 26, 2021
National	Oakland County, MI – Danielle Deneau	November 1, 2021
National	City of Raleigh, NC – Devin Smith	November 1, 2021
Nevada	RTC Washoe – Andrew Jayankura	October 19, 2021
Nevada	City of Henderson, NV – Eric Hawkins	October 20, 2021
Nevada	RTC Southern Nevada – John Penuelas	November 8, 2021
Nevada	City of Las Vegas, NV – Christina Karanikolas	December 8, 2021
Nevada	City of Sparks, NV – Amber Sosa	November 5, 2021
Nevada	City of Carson City, NV – Chris Martinovich	October 25, 2021
Nevada	Tahoe MPO – Melanie Sloan	October 25, 2021

Key Takeaways from Interviews

- PHBs are preferred for pedestrian crossings on high-speed arterials.
- Suburban locations with big box commercial stores on either side of the street are good candidates for PHBs.
- Other potential locations for PHBs include trail crossings and bike crossings.
- PHBs are preferred when pedestrian volumes are high or intermittently high.
- PHBs can be preferable when placed in close proximity to schools to deal with intermittently high volumes of pedestrians.
- Many agencies prefer PHBs for locations near entertainment venues such as theaters or stadiums.
- PHBs are preferred in locations where motorists may not expect a pedestrian or bicyclist to cross the road.

Desirable PHB Characteristics for Practitioners

- PHBs require traffic to stop, not yield, clearly designating right-of-way for the pedestrians.
- PHBs require all vehicular travel lanes to stop.
- PHBs have high conspicuity.

Undesirable PHB Characteristics for Practitioners

- Motorist familiarity can be low with PHBs.
- Pedestrians can be unfamiliar with how PHBs work.
- PHBs can often be expensive, depending on the location.
- PHB design and installation can be complex.

Rapid Rectangular Flashing Beacon (RRFB) Takeaways

- In contrast with PHBs, RRFBs are satisfactory for lower-speed, moderate vehicular volume applications, such as:
  - Residential collector streets.
  - Commercial areas.
  - Pedestrian paths, bike trails, etc.
- RRFBs are unsatisfactory on higher-speed arterials, such as:
  - Low motorist compliance, particularly for opposite-side traffic at single-stage crossings.
  - Visibility of pedestrians and signal heads can be poor on multilane roads particularly at single-stage crossings.

ATTACHMENT A

INTERVIEW SUMMARIES

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity		
Agency City of Austin	Interviewed By David Giacomin John Shaw	Interview Date Response
Respondent Name and Job Title Brian Craig	Respondent Phone and Email Phone: 512-974-4061 Email: brian.craig@austintexas.gov	

Approximate number of devices currently deployed (respondent's best estimate)									
RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
~12	~170	X	X	95	~30	X	X	X	X

Rectangular Rapid Flashing Beacons (RRFBs)

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Smaller roadways – collector roadways

Does agency have formal criteria for RRFB selection?

No formal criteria

"In its infancy" due to limited experience and inconsistency with other signal hardware. No audible feedback in current systems, some vendors offer APS. All current units are solar powered. Most are on stop-controlled streets.

Have there been operational or safety problems with RRFBs?

Earlier this year, installed 4 RRFBs on 3-lane roadways with medians; poles in the middle were struck multiple times. May not put middle pole in for small medians. None of RRFBs have overhead mast arms.

Is motorist compliance with RRFBs acceptable?

Concerned about low compliance. State law recently changed to require motorists to stop (previously required them to yield).

Are RRFBs accepted...

by the public?

Concerns from visually impaired people due to difficulty determining when the flasher is on.

Newness of device

by law enforcement?

No pushback

by senior management and political leadership?

No pushback

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals
Types of environments where PHB are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) 4-lane and 5-lane roadways, including TWLTLs. One site planned on a 7-lane roadway with a median. Concerned about long crossing times and visibility for very wide roads where a two-stage crossing cannot be supported. NOT used on 2- or 3-lane roadways due to resource constraints, NOT used on roadways +6 lanes, mainly due to lack of medians. As close as 300 ft from traffic signals, often adjacent to bus stops. Can be challenging to meet ped warrants based on volume, but there are two few gaps without the RPHBs (less than 20 gaps per hour). Land use is a consideration. Ped volume is not an overriding consideration, consider latent demand, consider land use adjacent to the corridor. Avoid putting them close to intersections if the PHB will be set up for a two-stage crossing, to avoid a situation that could be confusing to side-street traffic. Would prefer a full 12 foot width for the median, with a slight Z-crossing. Will be adding about 6 Z-crossings as part of an upcoming project.
Does agency have formal criteria for PHB selection? Vision Zero group is working on a criteria matrix to identify appropriate treatments for each type of device.
Are PHBs integrated with corridor or area-wide signal timing plans? Most of PHBs are at intersections. Some that are very close (less than ~350 ft) to traffic signal are integrated with signal timing plan, most are not and run free but have vehicle detection to delay the ped phase if a large platoon is approaching. Prefer to coordinate with signals to maximize vehicular flow, but peds will not wait very long. Peds maybe willing to wait ~30 sec.
Have there been operational or safety problems with PHBs? None known.
Is motorist compliance with PHBs acceptable? “Impressive” compliance – define compliance based on entry on red, the same as at a signalized intersection.

Are pedestrian hybrid beacons accepted...

by the public?

Have not received any complaints about the PHBs, have received a large number of requests for them. Have had some requests for PHBs in odd locations.

by law enforcement?

Neutral; did some early enforcement actions circa 2009-11 to help with compliance.

by senior management and political leadership?

No negative comments. 5-6 years ago the council members had some discretionary money and most districts submitted PHBs as candidate projects

If PHBs have not been used, why not?

- ☐ High cost
- ☐ Legal concerns (e.g., state laws related to dark signals)
- ☐ Political (external to agency)
- ☐ Political (internal to agency)
- ☐ Lack of awareness
- ☐ No perceived need
- ☐ Other reasons (specify):

Response

Other Signalized Pedestrian Crossings

Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Original PHB locations were locations that previously had overhead flashing yellow lights, but not sure whether they were ped-actuated or not.

Used to have some in-pavement flashers installed in mid-2000s, most have been removed due to maintenance problems.

Does agency have formal criteria for selection of other signalized pedestrian crossings?

Response

Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans?

Response

Have there been operational or safety problems with other signalized pedestrian crossings?

Response

Is motorist compliance with other signalized pedestrian crossings acceptable?

Response

Are other pedestrian signals accepted…

by the public?

Response

by law enforcement?

Response

by senior management and political leadership?

Response

General Questions

What would you do differently if you were starting again?

No change. One of the best tools to help pedestrians cross at locations away from traffic signals. Extremely impressed with PHB usefulness. Many sites have latent demand, varies by site. Some up to 10X more peds than before the RRFB was installed.

What else do practitioners need to know?

A lot easier to implement than in the past thanks to support from signal controller manufacturers.

AInterview Responses - Pedestrian Hybrid Beacons - Nevada DOT

<table>
<tr><th colspan="10">Respondent Identity</th></tr>
<tr><td colspan="4">Agency
City of Boca Raton, FL</td><td colspan="3">Interviewed By
John Shaw</td><td colspan="3">Interview Date
10/25/2021</td></tr>
<tr><td colspan="4">Respondent Name and Job Title
Maria Tejera, City Traffic Engineer</td><td colspan="6">Respondent Phone and Email
561-416-3369
MTejera@myboca.us</td></tr>
<tr><th colspan="10">Approximate number of devices currently deployed (respondent’s best estimate)</th></tr>
<tr><td colspan="2">RRFB</td><td colspan="2">Other Amber Beacons</td><td colspan="2">PHB (Hawk)</td><td colspan="2">British Designs Pelican, Puffin, etc.</td><td colspan="2">Other Multiphase Pedestrian Signals</td></tr>
<tr><td>Deployed
8-10</td><td>Planned
None</td><td>Deployed
X</td><td>Planned
X</td><td>Deployed
None</td><td>Planned
X</td><td>Deployed
X</td><td>Planned
X</td><td>Deployed
1</td><td>Planned
0</td></tr>
<tr><th colspan="10">Rectangular Rapid Flashing Beacons (RRFBs)</th></tr>
<tr><td colspan="10">Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)
Most are in the downtown area (Palmeto Park Rd) where there are heavier pedestrian flows. All sites are multilane with medians and are on long blocks, between signalized intersections.

One is on a trail crossing (shared use path crossing a collector).

All sites have medians, with two-stage crossings to avoid the problem of one direction stopping and not the other.</td></tr>
<tr><td colspan="10">Does agency have formal criteria for RRFB selection?
None. Funding is the main reason for selecting RRFBs; they are much less expensive than PHBs and are much faster to deploy.</td></tr>
<tr><td colspan="10">Have there been operational or safety problems with RRFBs?
No operational issues. Solar power is working acceptably due to limited tree cover.</td></tr>
<tr><td colspan="10">Is motorist compliance with RRFBs acceptable?
Compliance is not ideal. K-H did a compliance study. Usually the first drivers don’t stop, but eventually someone does. One of the main concerns is that traffic in one lane will stop, while traffic in the other lane keeps flowing. Will send a copy of the report.</td></tr>
<tr><td colspan="10">Are RRFBs accepted…

by the public?
Yes, public seems to like them.

by law enforcement?
Yes

by senior management and political leadership?
Yes</td></tr>
</table>

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals
None in use, but there are some in Miami, e.g. on Calle Ocho in nightlife district.
Does agency have formal criteria for PHB selection? N/A
Are PHBs integrated with corridor or area-wide signal timing plans? N/A
Have there been operational or safety problems with PHBs? N/A
Is motorist compliance with PHBs acceptable? N/A
Are pedestrian hybrid beacons accepted… by the public? N/A by law enforcement? N/A by senior management and political leadership? N/A
If PHBs have not been used, why not? ✓ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ✓ Other reasons (specify): Speed/ease of design and deployment (foundation, geotechnical, electrical supply, etc.)

Other Signalized Pedestrian Crossings

Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Three-phase ped signal at a trail crossing (same trail, different location)(El Rio Trail @ Congress). Unusual design with red wig-wag, yellow ball, and green ball. Very high volume (3 lanes in each direction), 45 mph route.

Three-phase mid-block signal for a school, located on a two-lane road with heavy traffic and a highway-like design.

Does agency have formal criteria for selection of other signalized pedestrian crossings?

No

Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans?

Response

Have there been operational or safety problems with other signalized pedestrian crossings?

No

Is motorist compliance with other signalized pedestrian crossings acceptable?

Response

Are other pedestrian signals accepted...

by the public?

Response

by law enforcement?

Response

by senior management and political leadership?

Response

General Questions

What would you do differently if you were starting again?

Decision is stipulated by funding – HAWK signals would be preferable, but the budget is not there.
What else do practitioners need to know? Will share RRFB compliance report prepared by Kimley-Horn.

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity		
Agency City of Memphis, TN	Interviewed By John Shaw	Interview Date 10/26/2021
Respondent Name and Job Title Nicholas Oyler Bikeway & Pedestrian Manager in Division of Engineering	Respondent Phone and Email	

Approximate number of devices currently deployed (respondent's best estimate)

RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
20	5+	-	-	3	2	-	-	2	0

Rectangular Rapid Flashing Beacons (RRFBs)

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Mid-block crossings such as shared use paths that intersect roadway, long blocks, 2-4 lane roadways, mostly on lower volume roadways local streets/collectors. A few on arterials, mainly where there is a refuge island in the middle (5 lanes, single stage crossing). Also have 1 set at a 7 lane roadway with a refuge island (two-stage crossing); this will be replaced with a PHB in the future.

Does agency have formal criteria for RRFB selection?

If roadway has 5+ lanes prefer a PHB, have used RRFBs in some cases in combination with a refuge island.

A couple of locations are in design with RRFBs that would be preferred as PHBs, but don't meet MUTCD criteria regarding 100 ft spacing to driveways. One is a 5-lane crossing, another is 6 lanes. These will have mast arms and poles in the median to provide better visibility. These will be convertible to PHBs if the MUTCD criteria change.

Have there been operational or safety problems with RRFBs?

No major issues. During initial installation there were some problems with the electronics.

Is motorist compliance with RRFBs acceptable?

Generally seem to be effective in increasing compliance, users generally understand how they are supposed to work with minimal education. Compliance is better when there are fewer lanes, compared to a 4-lane or divided context.

Are RRFBs accepted...

by the public?

Yes, no complaints/issues. Getting more and more requests from the public.

by law enforcement?
No complaints/issues.

by senior management and political leadership?
No complaints, getting requests to install in new locations.

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Two are on a popular greenway/ped path; these have several hundred users each day. One is 5 lane crossing of a major arterial with a raised refuge island, the other is a 4 lane crossing of an arterial without an island. ~20,000

Third location is unique: 5 lane roadway with two-way cycle track on one side, and a one-way bikeway on the other side. PHB allows bike traffic to cross the roadway. This is ~10,000 AADT.

Does agency have formal criteria for PHB selection?
Generally following MUTCD for PHBs, looser for RRFBs.

Are PHBs integrated with corridor or area-wide signal timing plans?
All 3 are running free, not coordinated with traffic signals. One of the PHBs in design now will be coordiated with a signal.

Have there been operational or safety problems with PHBs?
Operationally, some problems (greater than RRFBs). Greater need for public education on how drivers are supposed to respond. Often some confusion about meaning of solid red and flashing red phases, along with flashing yellow. Some drivers will treat solid red as a stop sign, some treat flashing red as mandatory to stay stopped. OK from a pedestrian perspective, esp. since countdown timers are included. Ped complaints are mainly about unexpected driver behavior.

Some PSAs when the PHBs were first installed (~2011).

No known crashes at any of the sites in past 7-8 years.

Is motorist compliance with PHBs acceptable?
Main problem is drivers not understanding the difference between flashing red and solid red phases.

Are pedestrian hybrid beacons accepted…

by the public?

Positive, general agreement from users that they stop car traffic and allow peds to cross safely. Have had requests to upgrade RRFBs to PHBs. Some complaints from drivers about having to make extra stops.

by law enforcement?

Similar to RRFBs: no complaints/concerns.

by senior management and political leadership?

No issues – requests to do more education for drivers. No complaints/hesitancy. Requests for additional PHB deployments. Some locations where staff would have liked a PHB, but division management did not approve it based on strict interpretation of MUTCD guidance (100 ft to cross street/driveway, count threshold). Tucson has several examples that are successful but don't meet those MUTCD requirements.

Consider need for overlap and flexibility in guidelines, and whether other countermeasures are in place (curb extensions, raised crossings, refuge islands).

If PHBs have not been used, why not?

- ☐ High cost
- ☐ Legal concerns (e.g., state laws related to dark signals)
- ☐ Political (external to agency)
- ☐ Political (internal to agency)
- ☐ Lack of awareness
- ☐ No perceived need
- ☐ Other reasons (specify):

Response

Other Signalized Pedestrian Crossings
Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Have a standard traffic signal at mid-block trail crossing for a busy 7-lane divided arterial (50 mph posted speed). Should probably be grade-separated, but that was not feasible. Two-phase with raised refuge island, coordinated with the two adjacent signal. This has existed since 2015 and has been successful. Works well. Proximity of other signals and desire for coordination probably drove the decision to use a traditional signal. High volume and speed were probably also criteria. Also have a standard signal near the University of Memphis on 4-lane divided road between main campus and main parking lot, near other signalized intersections. Installed more than 10 years ago. Embedded LEDs that flash continuously on some standard pedestrian crossings.
Does agency have formal criteria for selection of other signalized pedestrian crossings? Response
Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans? Response
Have there been operational or safety problems with other signalized pedestrian crossings? Response
Is motorist compliance with other signalized pedestrian crossings acceptable? Response
Are other pedestrian signals accepted… by the public? Response by law enforcement? Response by senior management and political leadership? Response
General Questions
What would you do differently if you were starting again? These treatments work, they are proven effective. They are necessary in many places due to the context of the roadway in order to provide safe ped crossings. Be open minded – they are effective.
What else do practitioners need to know? Consider RRFB with mast arm as an intermediate level treatment. Check NACTO guidance regarding this type of equipment. Matthew Roe @ NACTO (engineering expert – guideline developer).

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity									
Agency Oakland County (MI) Road Commission				Interviewed By John Shaw			Interview Date 11/01/21		
Respondent Name and Job Title Danielle Deneau Director of Traffic Safety (signs, signals, guard rails, pavement markings)				Respondent Phone and Email 248-858-4711 ddeneau@rcoc.org					
Approximate number of devices currently deployed (respondent's best estimate)									
RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
34	3	0	0	23	2	0	0	0	0

Rectangular Rapid Flashing Beacons (RRFBs)
Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Generally on lower speed facilities, which are 2-lane roads. Mostly 35 or 45 mph zones. MDOT installed a series of 2 or 3 RRFBs on Telegraph Road (M-24) along the Waterford-Pontiac border. At that location peds cross 7 lanes of traffic as a single-stage crossing (there is an island in the middle, but it does not have pedestrian pushbuttons). She considers this to be a poor choice of device type, and there is poor compliance by the traffic on opposite side of the road. The site does not have overhead beacons, but needs them. The RRFBs do not stand out from the adjoining visual clutter, in part due to the lack of overhead beacons.
Does agency have formal criteria for RRFB selection? Informal criteria based on speed. Safety is the county's top priority.
Have there been operational or safety problems with RRFBs? Some drivers (and pedestrians) don't seem to know what to do at an RRFB. The county has made some attempts to inform drivers and pedestrians how to use them. They have gotten some maintenance calls due to RRFBs "not working" when in fact the device is working properly but drivers are not stopping. Trying to avoid unnecessary maintenance calls by prescreening these contacts with local governments.
Is motorist compliance with RRFBs acceptable? The majority of drivers stop for pedestrians, but it depends on time of day and ped volumes. It can be hard for peds to cross during peak hours. Less compliance at higher volumes.
Are RRFBs accepted...

by the public?
Yes, “no news is good news.”

by law enforcement?
Agreeable.

by senior management and political leadership?
Agreeable, happy to have more attention drawn to pedestrians.

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals

Types of environments where PHBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)
12 of the 23 hawks are at *multilane* roundabouts (not used where there is only one lane at the approach to the splitter island). Most of the rest are at midblock locations on arterial roads. Many of these locations are trail crossings, mostly on 2-lane roads. A couple of the Hawk signals are on high-speed roads where it is not possible to direct the pedestrian traffic to a signalized intersection.

Trail crossings are in the more urban parts of the county, e.g. Birmingham.

Does agency have formal criteria for PHB selection?
Unofficial guideline: if speed limit is 45 mph or higher, use the Hawk signals. They do not think RRFBs provide enough protection for pedestrians on high-speed roads.

Need some flexibility to put up PHBs at locations that do not meet criteria for a regular traffic signal.

Are PHBs integrated with corridor or area-wide signal timing plans?
One installation has communications to the signal system and could potentially be coordinated. The remainder run free.

Have there been operational or safety problems with PHBs?
Had two locations that crossed a 50 mph boulevard, police were saying that drivers did not have enough time to react. They set the clearance intervals based on same procedures as traffic signals, or even increased the all-red phase an extra 1 second.

They have audible pushbuttons at roundabout locations. There was a problem with vandalism of the audible locator tone near a residential area, evidently because a resident was annoyed by the sound.

Is motorist compliance with PHBs acceptable?
No known crashes at PHBs. Perhaps some near-misses. Hawk signals at roundabouts – ped signal stays dark – two-stage crossing. At mid-block locations, don’t walk hand stays up until ped is authorized to cross.

Roundabouts are all two-stage crossings. Mid-block crossings (except 2) do not have pedestrian refuge islands. At all locations, traffic is stopped in both directions. Disruption to car traffic is minimal.
Are pedestrian hybrid beacons accepted… by the public? Good acceptance. Had a brochure that was distributed at the crossing to inform peds about how the signal works. Also tried to distribute some brochures to drivers. by law enforcement? At a location on a 50 mph road, the Sheriff wanted a regular traffic signal instead of a PHB. After about a week, drivers got used to it and the concern disappeared. by senior management and political leadership? Monitoring, e.g. for walking speed. Most elected officials are excited to have the device and to be seen doing something for pedestrian safety.
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify): X

Other Signalized Pedestrian Crossings
Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) X
Does agency have formal criteria for selection of other signalized pedestrian crossings? X
Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans? X
Have there been operational or safety problems with other signalized pedestrian crossings? X
Is motorist compliance with other signalized pedestrian crossings acceptable? X
Are other pedestrian signals accepted... by the public? X by law enforcement? X by senior management and political leadership? X

General Questions
What would you do differently if you were starting again? When they first started, they were not sure whether RRFBs and PHBs would work on their roads. Close coordination with local governments has been valuable – local governments are often installing the signal, and the county maintains it. This has contributed to standardization across the county, both in terms of the appearance and operation of the signal, and maintainability (standardizing components to unify spare parts inventory and assure that maintenance technicians are familiar with the equipment). The buy-in from municipalities has contributed to good public relations and outreach. Process: Municipality requests the device, Oakland County issues a permit to install the device, municipality pays for installation, Oakland County maintains at local expense.
What else do practitioners need to know? 30 second minimum time between actuations for Hawk signals – avoids problems with stuck buttons or big groups of peds. Otherwise, timed like a regular traffic signal (clearance intervals like a signal).

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity

Agency	Interviewed By	Interview Date
City of Raleigh, NC	John Shaw David Veneziano	01-Nov-2021

Respondent Name and Job Title	Respondent Phone and Email
Devin Smith Senior Traffic Engineer (signal design and timing)	919-996-4062 devin.smith@raleighnc.gov

Approximate number of devices currently deployed (respondent's best estimate)

RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
Not sure	Not sure	-	-	15	A few more	-	-	~5	-

Rectangular Rapid Flashing Beacons (RRFBs)

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

X

Does agency have formal criteria for RRFB selection?

X

Have there been operational or safety problems with RRFBs?

X

Is motorist compliance with RRFBs acceptable?

X

Are RRFBs accepted...

by the public?

X

by law enforcement?

X

by senior management and political leadership?

X

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals

Types of environments where PHBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Mainly on 4+ lanes (2 per direction), especially near schools, greenways, hospitals, university. Mix of high and moderate volumes. Some have higher pedestrian volumes.

Recently installed two on greenways (multi-use trails) in response to fatalities. Thinking about putting them in on all greenways to improve overall pedestrian safety. Locations where drivers might not

be expecting a pedestrian. All are single-stage crossings. Many have a pedestrian pushbutton in the median, but it activates both sides because they prefer single stage crossings.
Does agency have formal criteria for PHB selection? No
Are PHBs integrated with corridor or area-wide signal timing plans? A few are tied to corridor signal timing plans, for example one is near a mall. Had problem with peds not waiting more than 60 seconds without forcing gaps. Also have some locations that were originally tied to a corridor signal plan, but wait times were too long; at these sites they went to half-cycle or running free. Had one on an 80 second cycle, which was problematic for ped compliance. Prefer 60 sec or less, maybe 70-75 seconds at the longest.
Have there been operational or safety problems with PHBs? No problems, except pedestrian non-compliance when the cycle length is long (more than 60 sec).
Is motorist compliance with PHBs acceptable? Issue with signal near mall – motorists tend to ignore the crosswalk. Tried letting it run free, but got complaints from motorists.
Are pedestrian hybrid beacons accepted… by the public? No issues. Had a Hawk (or maybe more than one?) by elementary school that was too close to a signalized intersection – converted it to a regular signal. by law enforcement? No issues. by senior management and political leadership? No issues – desire to be pedestrian friendly.
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify):

Other Signalized Pedestrian Crossings

Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Near schools – especially where there are pedestrian issues.

Does agency have formal criteria for selection of other signalized pedestrian crossings?

No

Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans?

X

Have there been operational or safety problems with other signalized pedestrian crossings?

X

Is motorist compliance with other signalized pedestrian crossings acceptable?

X

Are other pedestrian signals accepted…

by the public?

X

by law enforcement?

X

by senior management and political leadership?

X

General Questions

What would you do differently if you were starting again?

Training videos to improve driver familiarity with the Hawk – need for better pedestrian awareness. Coordination with schools so students know how to use the signal.

Ped safety is a big challenge in Raleigh. Have had some fatalities involving student non-use of ped signals generally. City council is trying to make the city more ped friendly, for example by implementing leading pedestrian intervals at many signals. Most arterials are 35 mph to 45 mph, sometimes actual speeds are 55-60 mph.

What else do practitioners need to know?

Some communities (groups of road users) tend not to use Hawks, for example some specific Hawk signals are underutilized by lower-income pedestrians, homeless people, etc.

There is a fair amount of confusion about pedestrian signals generally, for example what the countdown means, the meaning of the different displays.

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity		
Agency City of Henderson	Interviewed By David Giacomin	Interview Date October 20, 2021
Respondent Name and Job Title Eric Hawkins	Respondent Phone and Email eric.hawkins@cityofhenderson.com	

Approximate number of devices currently deployed (respondent's best estimate)									
RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed 50-75	Planned Yes	Deployed	Planned	Deployed *2*	Planned *1*	Deployed	Planned	Deployed	Planned

Rectangular Rapid Flashing Beacons (RRFBs)
Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) RRFBs are deployed in numerous locations and environments throughout Henderson.
Does agency have formal criteria for RRFB selection? NDOT: Pedestrian Safety Improvement Evaluation Guideline for Uncontrolled Crossings.
Have there been operational or safety problems with RRFBs? The City is not aware of any operational or safety problems with RRFBs.
Is motorist compliance with RRFBs acceptable? There are not many complaints about non-compliance with RRFBs.
Are RRFBs accepted… by the public? 7-8 RRFBs around the Anthem Loop. There are concerns about visibility during dusk/dawn. by law enforcement? No concerns noted by law enforcement. by senior management and political leadership? No concerns by political leadership/management.

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals
Types of environments where PHB are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Foothill HS (College and Vermillion) Greenspun Junior HS (Valle Verde and Wigwam) Green Valley HS(Warm Springs and Arroyo Grande PLANNED) Same sequence as HAWK
Does agency have formal criteria for PHB selection? Not formal, led by citizen and staff concern, for locations with high pedestrian volumes at certain times, with the benefit of maintaining some level of traffic flow. Pedestrian Safety Improvement Evaluation Guideline for Uncontrolled Crossings.
Are PHBs integrated with corridor or area-wide signal timing plans? No

Have there been operational or safety problems with PHBs? Not that they are aware of.
Is motorist compliance with PHBs acceptable? Unsure about compliance for the College location, Valle Verde has good compliance. Prior to implementation, these locations had signed crosswalks with no signal/lights.
Are pedestrian hybrid beacons accepted… by the public? The general public has not voiced any concerns. Erin Breen noted that pedestrian groups hold a favorable view of the Valle Verde location. by law enforcement? Law enforcement has not voiced any concerns about these locations. by senior management and political leadership? Viewed favorably by the city, no concerns have been voiced by political leadership.
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify): Cost was a concern with the implementation of a full PHB. Valle Verde is a solar-powered system which likely reduced cost of construction.

Other Signalized Pedestrian Crossings
Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Response
Does agency have formal criteria for selection of other signalized pedestrian crossings? Response
Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans? Response
Have there been operational or safety problems with other signalized pedestrian crossings? Response
Is motorist compliance with other signalized pedestrian crossings acceptable? Response
Are other pedestrian signals accepted… by the public? Response by law enforcement? Response by senior management and political leadership? Response
General Questions
What would you do differently if you were starting again? Response
What else do practitioners need to know?

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity		
Agency City of Las Vegas	Interviewed By David Giacomin	Interview Date December 8, 2021
Respondent Name and Job Title Christina Karanikolas	Respondent Phone and Email 702-229-1089, ckaranikolas@lasvegasnevada.gov	

Approximate number of devices currently deployed (respondent's best estimate)

RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
32	Yes			*1*	*2*				

Rectangular Rapid Flashing Beacons (RRFBs)

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

RRFBs have been deployed in numerous types of locations.

Does agency have formal criteria for RRFB selection?

The agency has not used formal criteria in the past but is aware of the NDOT: Pedestrian Safety Improvement Evaluation Guideline for Uncontrolled Crossings.

Have there been operational or safety problems with RRFBs?

The agency notes that compliance/stopping is sometimes an issue with RRFBs.

Is motorist compliance with RRFBs acceptable?

There are not many complaints about non-compliance with RRFBs.

Are RRFBs accepted...

by the public?

Yes, no comments from the public.

by law enforcement?

Response

Yes, law enforcement says compliance is good.

by senior management and political leadership?

There have been no political discussions about RRFBs

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals

Types of environments where PHB are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Sahara and 15th. City has appetite for more PHBs. Currently scoping for 2 more PHBs. Interested in PHBs when a signal is not feasible.

Does agency have formal criteria for PHB selection?

No formal criteria

Are PHBs integrated with corridor or area-wide signal timing plans?

No

Have there been operational or safety problems with PHBs?

No issues noted.

Is motorist compliance with PHBs acceptable?

Compliance is generally good, and the PHB has been deployed for many years.

Are pedestrian hybrid beacons accepted...

by the public?

Per the City of Las Vegas in April 2024: "Currently the City has 2 PHBs under active construction: Sahara/Las Verdes & Durango/Dorrell (these are both conversions from RRFBs). The City also has at least 2 PHBs slated for design: Buffalo/Del Rey and Rainbow/Peak."

The public generally accepts PHBs. No complaints are noted. by law enforcement? Law enforcement says compliance is great and they do not have any concerns. by senior management and political leadership? No concerns have been voiced by political leadership.
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify): Cost is fairly high for the City of Las Vegas, and they often struggle to justify the implementation of a PHB in comparison to a full signal. However they are seeking to implement more, particularly where signals are not feasible but pedestrian volumes are high.

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity		
Agency RTC Southern Nevada	Interviewed By Response	Interview Date November 8, 2021
Respondent Name and Job Title John Penuelas	Respondent Phone and Email penuelasj@rtcsnv.com	

Approximate number of devices currently deployed (respondent's best estimate)									
RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
100s	Yes	X	X	1	-	X	X	X	X

Rectangular Rapid Flashing Beacons (RRFBs)
Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) RRFBs are deployed in locations where existing pedestrian volumes are high, which is frequently close to transit facilities as well as mixed land use areas.
Does agency have formal criteria for RRFB selection? The RTC does not.
Have there been operational or safety problems with RRFBs? The agency was not aware of any safety or operational problems.
Is motorist compliance with RRFBs acceptable? Compliance is not 100%, but it is high.
Are RRFBs accepted… by the public? Response has been largely positive by law enforcement? None known by senior management and political leadership? None known

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals
Types of environments where PHB are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Response
Does agency have formal criteria for PHB selection? Response
Are PHBs integrated with corridor or area-wide signal timing plans? Response
Have there been operational or safety problems with PHBs? Response
Is motorist compliance with PHBs acceptable? Response

Are pedestrian hybrid beacons accepted… by the public? There was some operational opposition (Mike Jansen) within the RTC after installation of the Sahara PHB regarding the coordinated system along Sahara. Concerns were largely technical ones within the RTC. Avoid locations with coordinated systems. by law enforcement? No known opposition by senior management and political leadership? No known opposition
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify): Response Political will appears to exist, possible lack of resources is slowing the process.

Other Signalized Pedestrian Crossings
Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) Response
Does agency have formal criteria for selection of other signalized pedestrian crossings? Response
Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans? Response
Have there been operational or safety problems with other signalized pedestrian crossings? Response
Is motorist compliance with other signalized pedestrian crossings acceptable? Response
Are other pedestrian signals accepted… by the public? Response by law enforcement? Response by senior management and political leadership? Response
General Questions
What would you do differently if you were starting again? Response
What else do practitioners need to know? There were some in-ground lighting deployments in Henderson that are no longer in use and were replaced by RRFBs. Worth following-up on this.

Interview Responses - Pedestrian Hybrid Beacons - Nevada DOT

Respondent Identity

Agency	Interviewed By	Interview Date
RTC Washoe	David Giacomin	Andrew Jayankura

Respondent Name and Job Title	Respondent Phone and Email
Andrew Jayankura Project Manager	ajayankura@rtcwashoe.com

Approximate number of devices currently deployed (respondent's best estimate)

RRFB		Other Amber Beacons		PHB (Hawk)		British Designs Pelican, Puffin, etc.		Other Multiphase Pedestrian Signals	
Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned	Deployed	Planned
Yes	Yes	Yes						Yes	

Rectangular Rapid Flashing Beacons (RRFBs)

Types of environments where RRFBs are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

RRFBs have been deployed in multiple locations in accordance with guidelines set within NDOT: Pedestrian Safety Improvement Evaluation Guideline for Uncontrolled Crossings.

Does agency have formal criteria for RRFB selection?

RTC Washoe uses NDOT: Pedestrian Safety Improvement Evaluation Guideline for Uncontrolled Crossings and works with the local city to identify locations for RRFBs, who then follow FHWA criteria. RTC Washoe tries to not place them too close together.

Have there been operational or safety problems with RRFBs?

RTC Washoe has issues with timing, sometimes flashing occurs for too long. Sometimes activation of RRFBs can cause operational issues with downstream signals.

Is motorist compliance with RRFBs acceptable?

Compliance is generally pretty good.

Are RRFBs accepted...

by the public?

Yes, the public generally accepts them.

by law enforcement?

Law enforcement has not made any complaints.

by senior management and political leadership?

Yes, responses are positive.

Pedestrian Hybrid Beacons (PHBs) / Hawk Signals

Types of environments where PHB are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.)

Response

Does agency have formal criteria for PHB selection?

Response

Are PHBs integrated with corridor or area-wide signal timing plans?

Response

Have there been operational or safety problems with PHBs?

Response

Is motorist compliance with PHBs acceptable? Response
Are pedestrian hybrid beacons accepted… by the public? Response by law enforcement? Response by senior management and political leadership? Response
If PHBs have not been used, why not? ☐ High cost ☐ Legal concerns (e.g., state laws related to dark signals) ☐ Political (external to agency) ☐ Political (internal to agency) ☐ Lack of awareness ☐ No perceived need ☐ Other reasons (specify): Response RTC Washoe is currently unsure as to why they do not have PHBs.

Other Signalized Pedestrian Crossings
Types of environments where other signalized pedestrian crossings are deployed (land use, motor vehicle volume, pedestrian volume, presence of transit stops, etc.) The local jurisdiction has deployed other signalized pedestrian crossings in areas of schools as well as in mid to high density residential areas with adjacent roads that have speed limits greater than 25 mph and at least two lanes in each direction.
Does agency have formal criteria for selection of other signalized pedestrian crossings? No.
Are other signalized pedestrian crossings integrated with corridor or area-wide signal timing plans? No.
Have there been operational or safety problems with other signalized pedestrian crossings? Not that agency is currently aware of.
Is motorist compliance with other signalized pedestrian crossings acceptable? For the most part yes.
Are other pedestrian signals accepted… by the public? Generally yes. by law enforcement? Yes. by senior management and political leadership? Response
General Questions
What would you do differently if you were starting again? Wishes to have more flexibility in choosing which type of crossing to implement, and to be more strategic regarding location selection for deployment.
What else do practitioners need to know?

APPENDIX D

NEVADA PEDESTRIAN TREATMENT EVALUATION WORKBOOK

Nevada Pedestrian Treatment Evaluation Worksheet

Version 0.6

Site Characteristics

Project Number	Site Description	
1	**MLK Boulevard at Balzar Avenue**	
Date	Analyst/Notes	
12/13/2022	D. Giacomin	
Roadway Type		Urban/Suburban Arterial
Configuration		Divided: 3 Lanes per Direction
Speed Range (mph)		30-35
V: Motor Vehicle Volume - Annual Average Daily Traffic (AADT)		40,500
P: Pedestrians Crossing Per Hour (Peak Hour)*		13
X: Pedestrian eXpansion Factor		Default (10.0)
Expansion Factor	10.0	
PX: Pedestrian Crossings per Day		130
PXV: Vehicle-Pedestrian Exposures per Day		5,265,000
Motor Vehicle Traffic Growth Rate		Default (2.0%)
Annual Growth Rate	2.0%	
Pedestrian Traffic Growth Rate		Default (3.0%)
Annual Growth Rate	3.0%	

* Observed pedestrian count or estimated count including increases due to improved pedestrian access. Highly vulnerable road users such as children, visually impaired people, and people with mobility impairment should be counted as double.

Potential Treatments & Treatment Enhancements

Star Rating	**Treatment Description**	**Relative Cost**
-		
-		
-		
☆☆	Enhanced pedestrian-activated amber beacon (EAB)	$$$
☆☆☆☆☆	Pedestrian hybrid beacon (PHB)	$$$$
☆☆☆☆☆	Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style	$$$$
☆☆☆☆☆	Mid-block signal (MBS) – MUTCD Style	$$$$
☆☆☆☆☆	Grade Separation (GS)	$$$$$
-		
☆☆☆☆☆	[Treatment] + median refuge	$$
-		

Selected Treatment

Treatment Type	**Rectangular Rapid Flashing Beacon (RRFB) - Mast Arm - 35 mph or lower**	
Project Cost in 2022 dollars	Default	
Installation (one-time)	$12,500	
Maintenance & Ops (yearly)	$250	
Service Life (years)	20	
Crash Modification Factors	Default	
(0.00 = complete elimination of all crashes, 1.00 = no effect)		
Fatalities	0.45	
Serious Injuries	0.45	
Minor Injuries	0.45	

Economic Analysis Parameters

Project Completion Year		2024
Project Completion Month		December
Base Year for Economic Computations		2022
Real discount rate for future-year benefits and costs		1.07%

2022 Total costs per exposure		$0.0120
From fatalities	$0.0091	
From serious injuries	$0.0018	
From minor injuries	$0.0010	
Pre-intervention Annual Pedestrian Casualty Risk		$63,011
From fatalities	$48,090	
From serious injuries	$9,430	
From minor injuries	$5,491	
Post-intervention Annual Pedestrian Casualty Risk		$28,544
From fatalities	$21,785	
From serious injuries	$4,272	
From minor injuries	$2,487	
First-Year Change in Pedestrian Risk (negative values indicate improved ped safety)		-$34,467

Economic Analysis Results

Year	Benefits	Costs
2024	$0	$12,235
2025	$35,825	$247
2026	$37,237	$245
2027	$38,704	$242
2028	$40,229	$240
2029	$41,814	$237
2030	$43,461	$234
2031	$45,174	$232
2032	$46,953	$229
2033	$48,803	$227
2034	$50,726	$225
2035	$52,725	$222
2036	$54,802	$220
2037	$56,962	$217
2038	$59,206	$215
2039	$61,539	$213
2040	$63,963	$211
2041	$66,484	$208
2042	$69,103	$206
2043	$71,826	$204
2044	$74,656	$202
2045	$0	$0
2046	$0	$0
2047	$0	$0
2048	$0	$0
2049	$0	$0
<==Click to Expand		
Totals in 2022 dollars	**$1,060,191**	**$16,711**
Benefit/Cost Ratio		**63.4**
Net Present Value		$1,043,479
Internal Rate of Return		294.8%

Nevada Pedestrian Treatment Evaluation Worksheet

Version 0.6

Site Characteristics

Project Number	Site Description	
2	**Bonanza Road and 23rd Street**	
Date	Analyst/Notes	
12/13/2022	D. Giacomin	
Roadway Type		Urban/Suburban Arterial
Configuration		Undivided: 5 to 6 Lanes
Speed Range (mph)		30-35
V: Motor Vehicle Volume - Annual Average Daily Traffic (AADT)		19,550
P: Pedestrians Crossing Per Hour (Peak Hour)*		48
X: Pedestrian eXpansion Factor		Default (10.0)
Expansion Factor	10.0	
PX: Pedestrian Crossings per Day		480
PXV: Vehicle-Pedestrian Exposures per Day		9,384,000
Motor Vehicle Traffic Growth Rate		Default (2.0%)
Annual Growth Rate	2.0%	
Pedestrian Traffic Growth Rate		Default (3.0%)
Annual Growth Rate	3.0%	

* Observed pedestrian count or estimated count including increases due to improved pedestrian access. Highly vulnerable road users such as children, visually impaired people, and people with mobility impairment should be counted as double.

Potential Treatments & Treatment Enhancements

Star Rating	**Treatment Description**	**Relative Cost**
-		
-		
-		
☆	Enhanced pedestrian-activated amber beacon (EAB)	$$$
☆☆☆☆☆	Pedestrian hybrid beacon (PHB)	$$$$
☆☆☆☆	Mid-Block Pedestrian Signal (MBPS) – Los Angeles Style	$$$$
☆☆☆☆☆	Mid-block signal (MBS) – MUTCD Style	$$$$
☆☆☆☆☆	Grade Separation (GS)	$$$$$
-		
☆☆☆☆☆	[Treatment] + median refuge	$$
-		

Selected Treatment

Treatment Type	**Pedestrian Hybrid Beacon (PHB): Stand-Alone**	
Project Cost in 2022 dollars	Default	
Installation (one-time)	$300,000	
Maintenance & Ops (yearly)	$6,000	
Service Life (years)	25	
Crash Modification Factors	Default	
(0.00 = complete elimination of all crashes, 1.00 = no effect)		
Fatalities	0.54	
Serious Injuries	0.54	
Minor Injuries	0.54	

Economic Analysis Parameters

Project Completion Year		2023
Project Completion Month		June
Base Year for Economic Computations		2022
Real discount rate for future-year benefits and costs		1.07%

2022 Total costs per exposure		$0.0120
From fatalities	$0.0091	
From serious injuries	$0.0018	
From minor injuries	$0.0010	
Pre-intervention Annual Pedestrian Casualty Risk		$112,307
From fatalities	$85,713	
From serious injuries	$16,808	
From minor injuries	$9,787	
Post-intervention Annual Pedestrian Casualty Risk		$60,983
From fatalities	$46,542	
From serious injuries	$9,127	
From minor injuries	$5,314	
First-Year Change in Pedestrian Risk (negative values indicate improved ped safety)		-$51,324

Economic Analysis Results

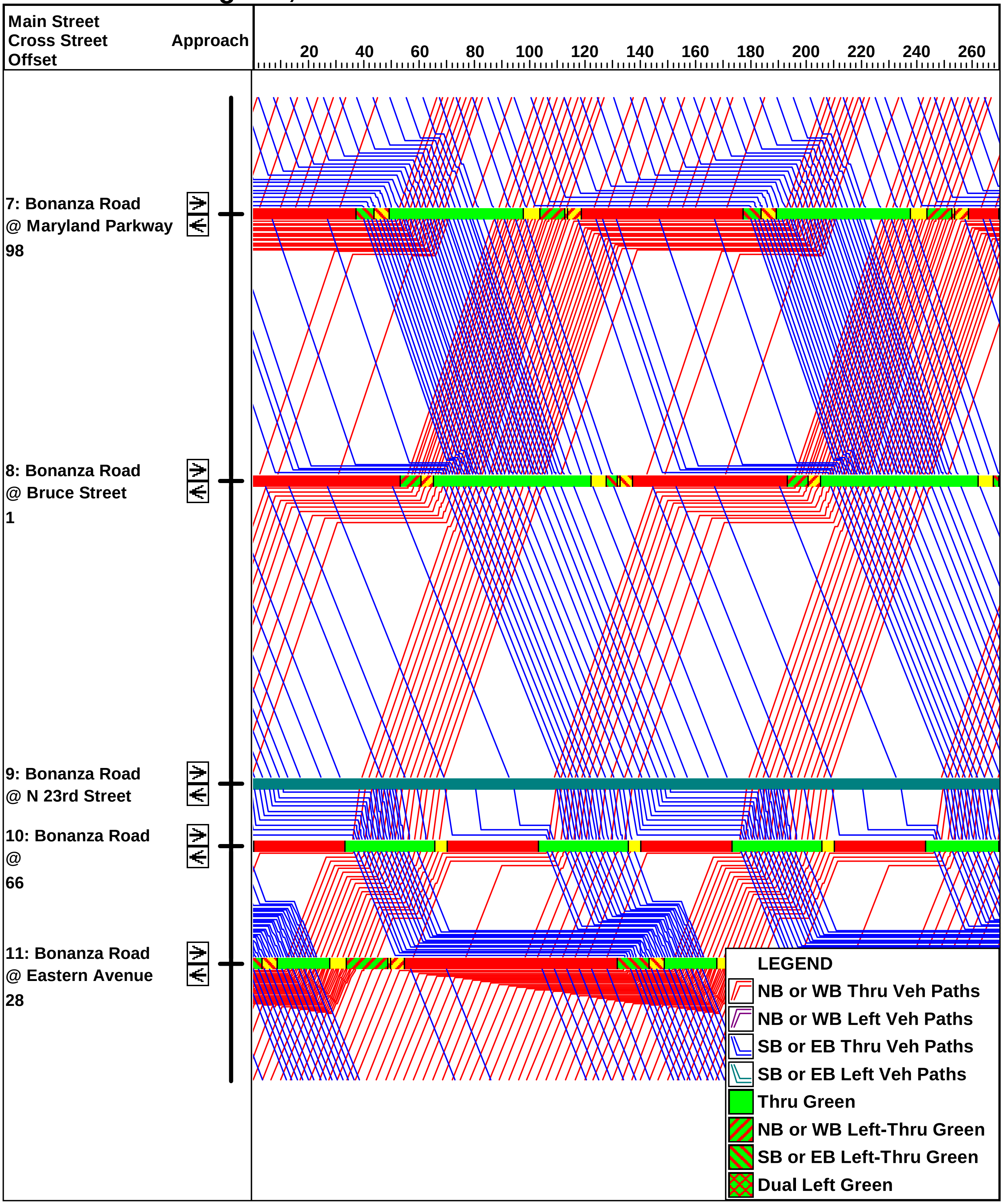
Year	Benefits	Costs
2023	$25,389	$299,770
2024	$53,346	$5,936
2025	$55,448	$5,873
2026	$57,633	$5,810
2027	$59,904	$5,748
2028	$62,264	$5,687
2029	$64,717	$5,626
2030	$67,267	$5,566
2031	$69,918	$5,507
2032	$72,672	$5,448
2033	$75,536	$5,390
2034	$78,512	$5,333
2035	$81,605	$5,276
2036	$84,820	$5,220
2037	$88,162	$5,164
2038	$91,636	$5,109
2039	$95,247	$5,055
2040	$98,999	$5,001
2041	$102,900	$4,947
2042	$106,954	$4,895
2043	$111,168	$4,842
2044	$115,548	$4,791
2045	$120,101	$4,740
2046	$124,833	$4,689
2047	$129,752	$4,639
2048	$134,864	$4,590
<==Click to Expand		
Totals in 2022 dollars	**$2,229,197**	**$430,652**
Benefit/Cost Ratio		**5.2**
Net Present Value		$1,798,545
Internal Rate of Return		21.3%

APPENDIX E

TIME-SPACE DIAGRAMS FOR TEST CORRIDORS

Time-Space Diagram - Bonanza Road

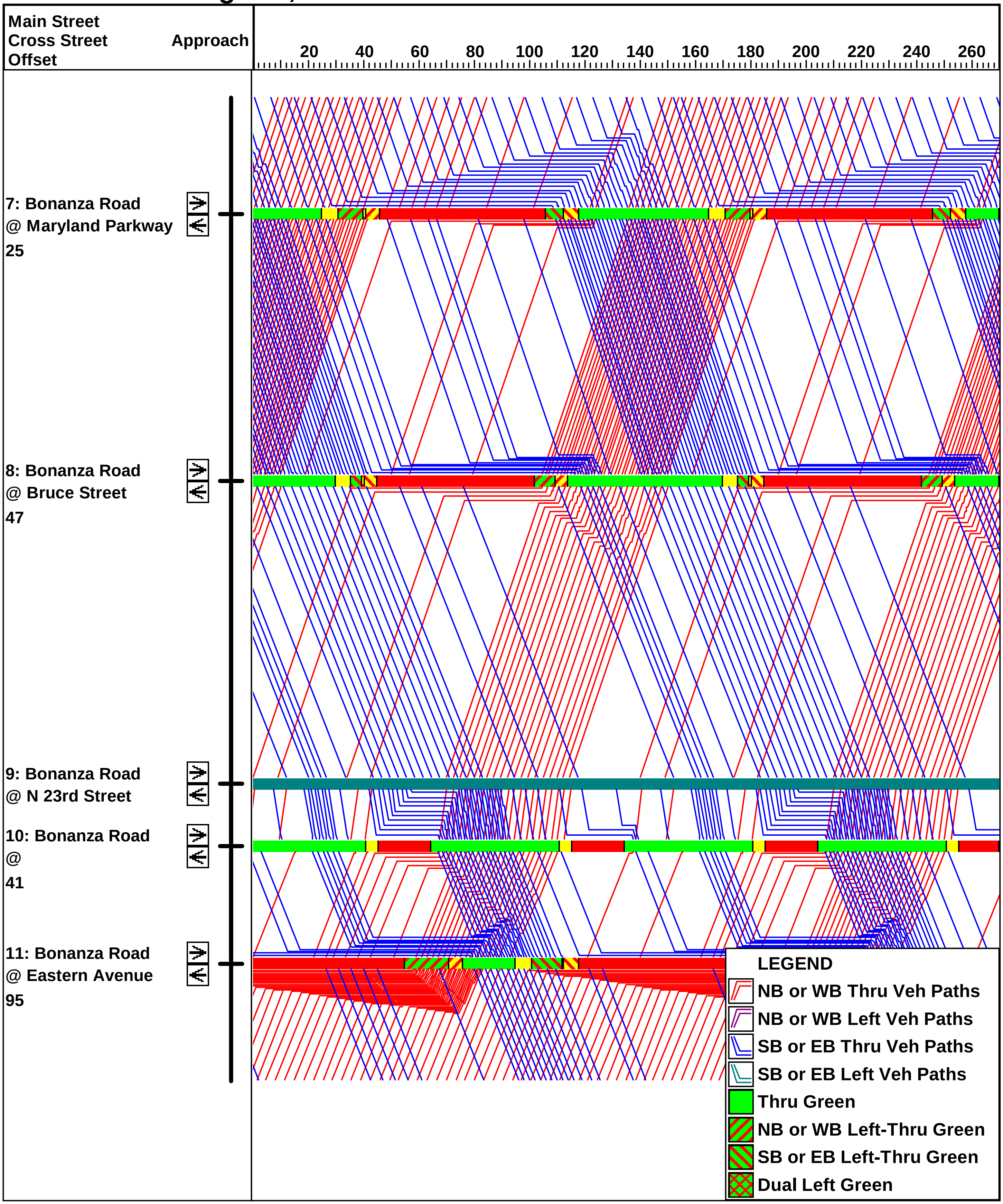
Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



PM+0 1-Stage

Time-Space Diagram - Bonanza Road

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



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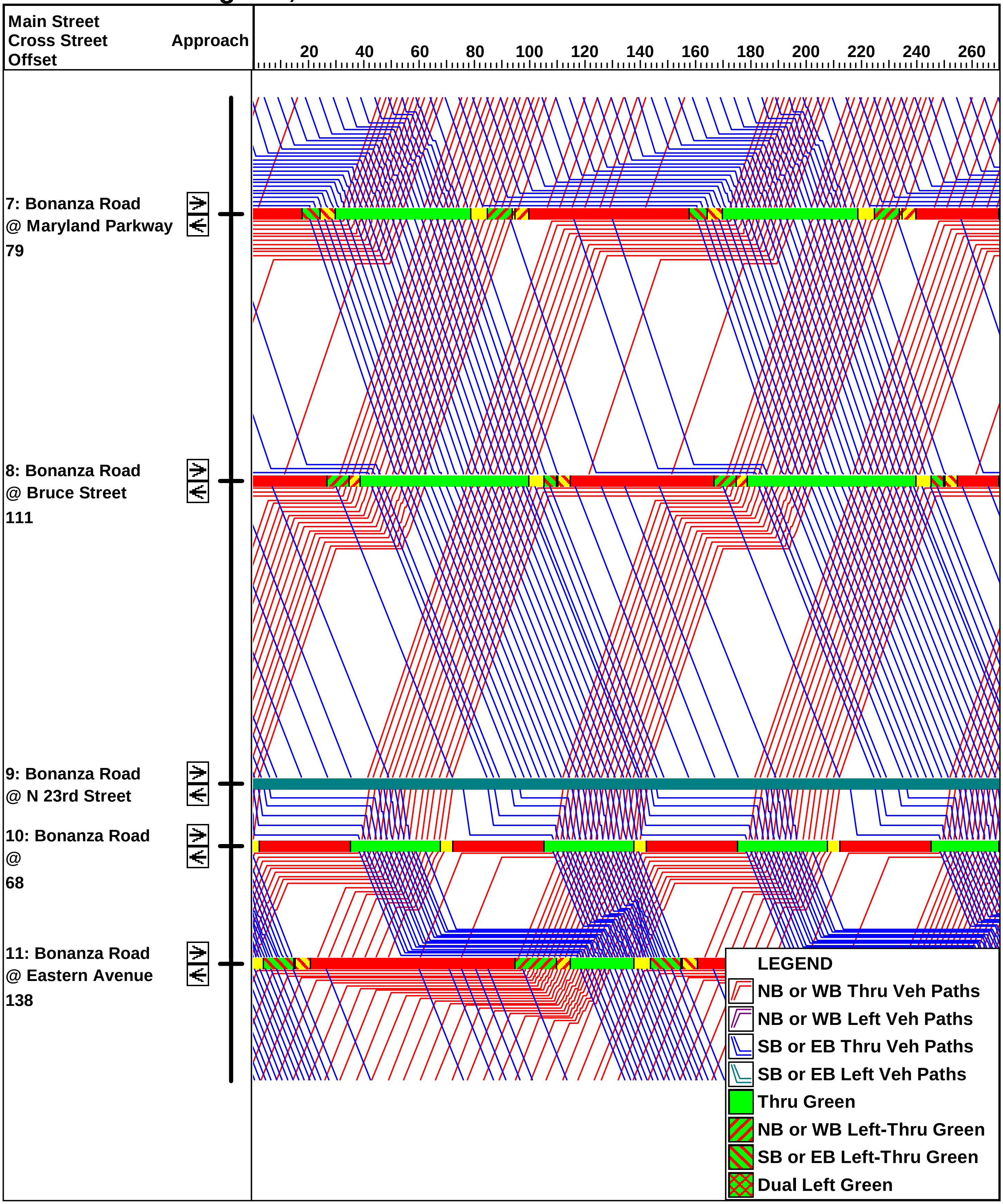
Time-Space Diagram - Bonanza Road

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



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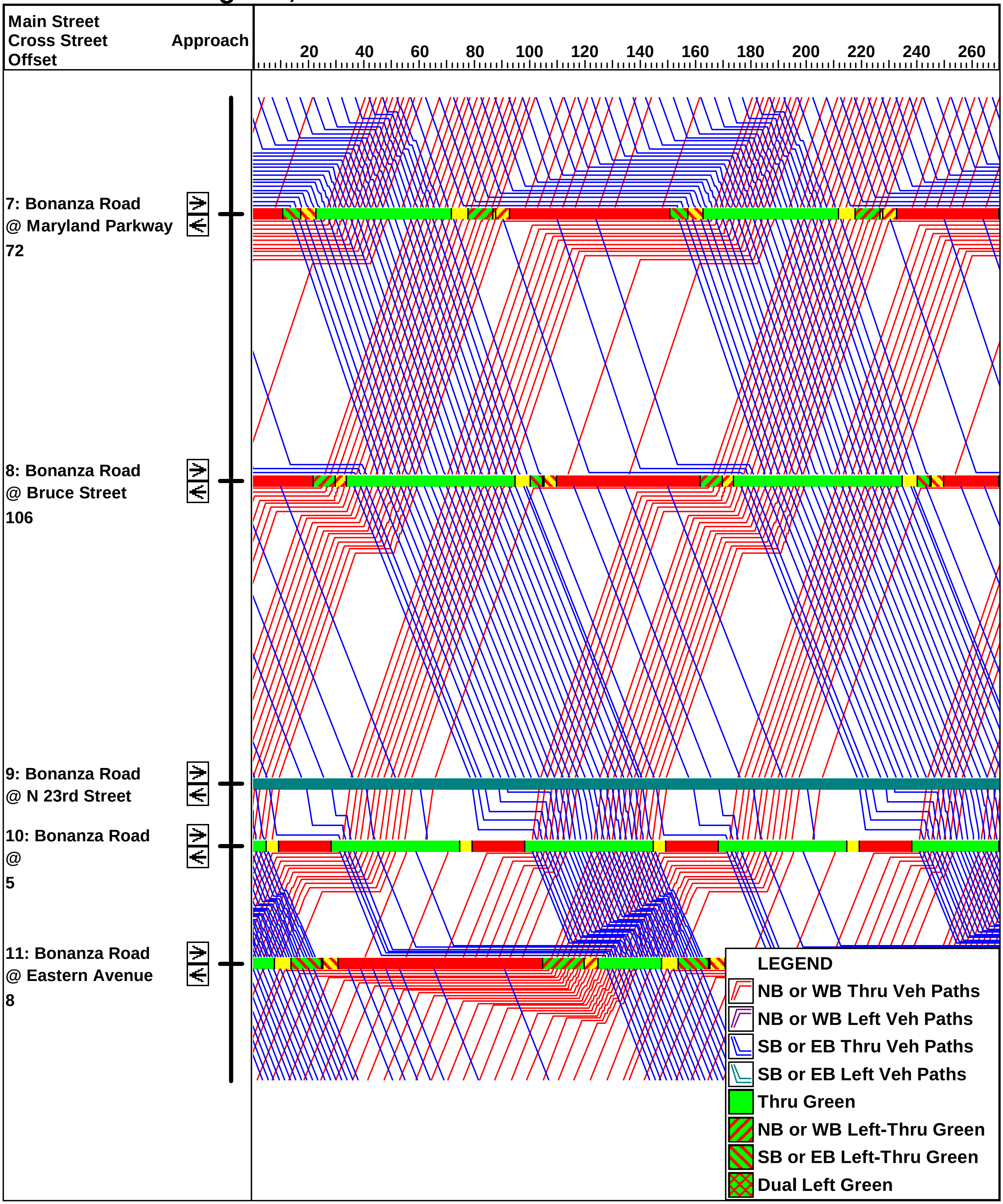
Time-Space Diagram - Bonanza Road

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



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Time-Space Diagram - Bonanza Road

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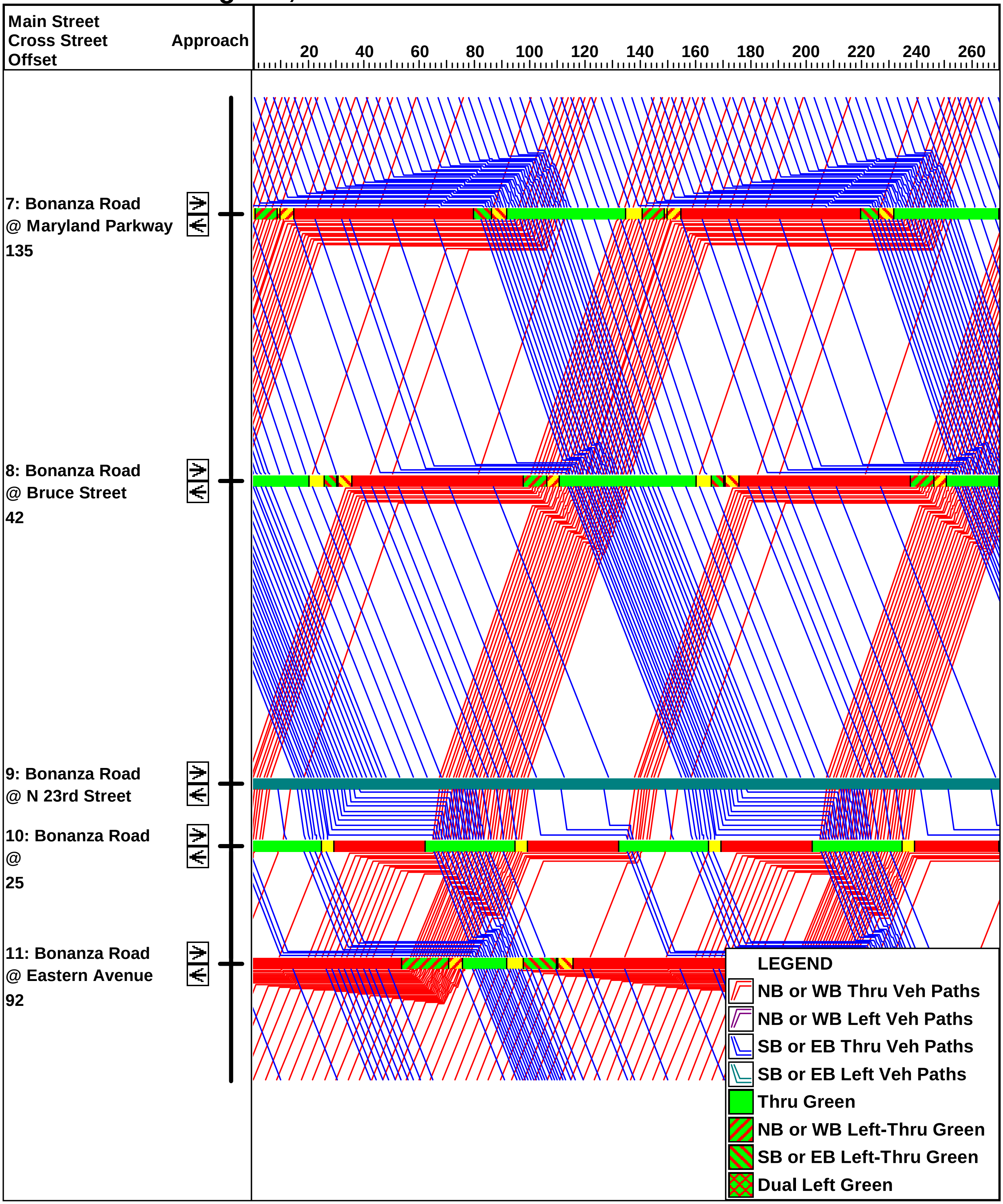

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Time-Space Diagram - Bonanza Road

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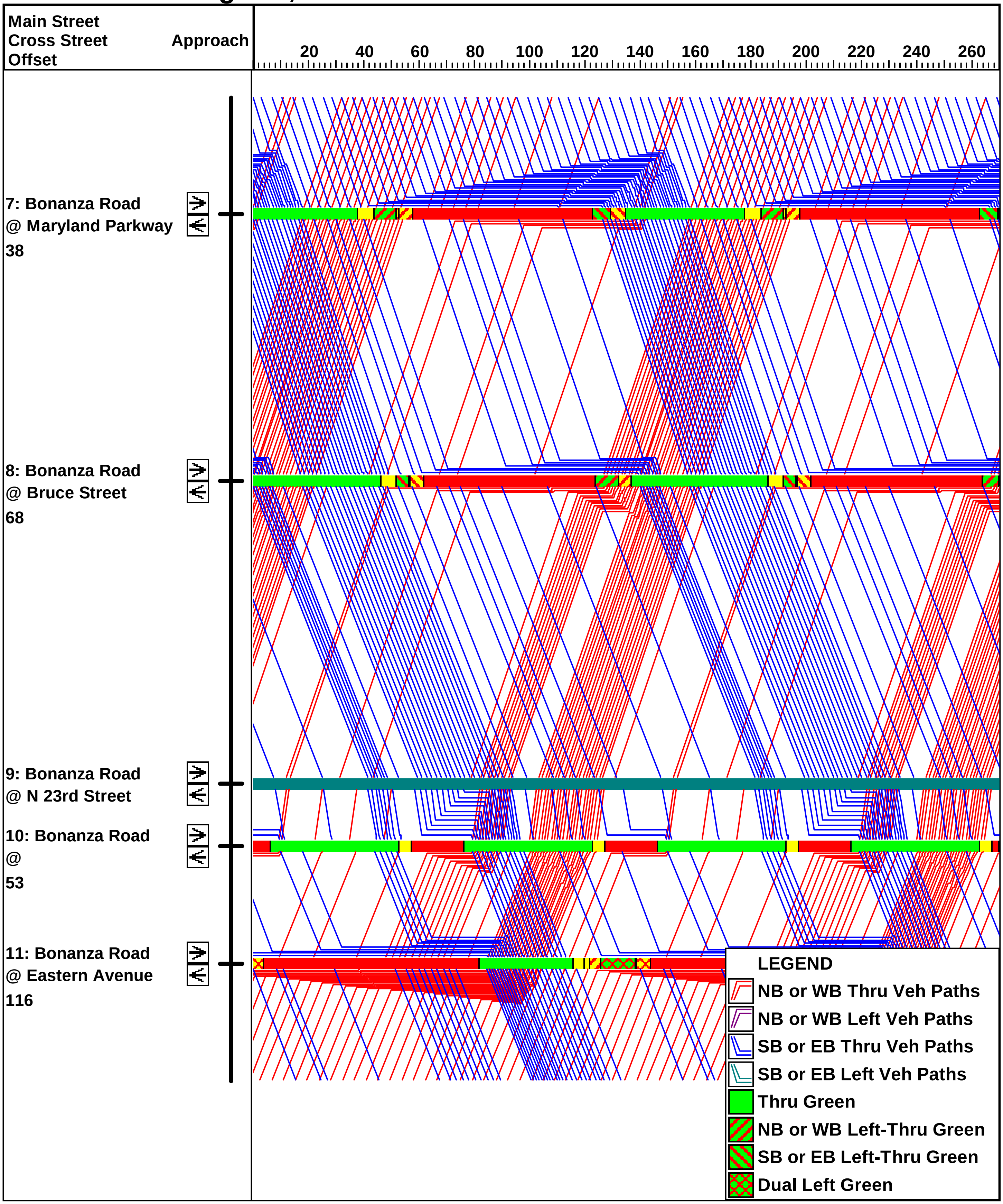
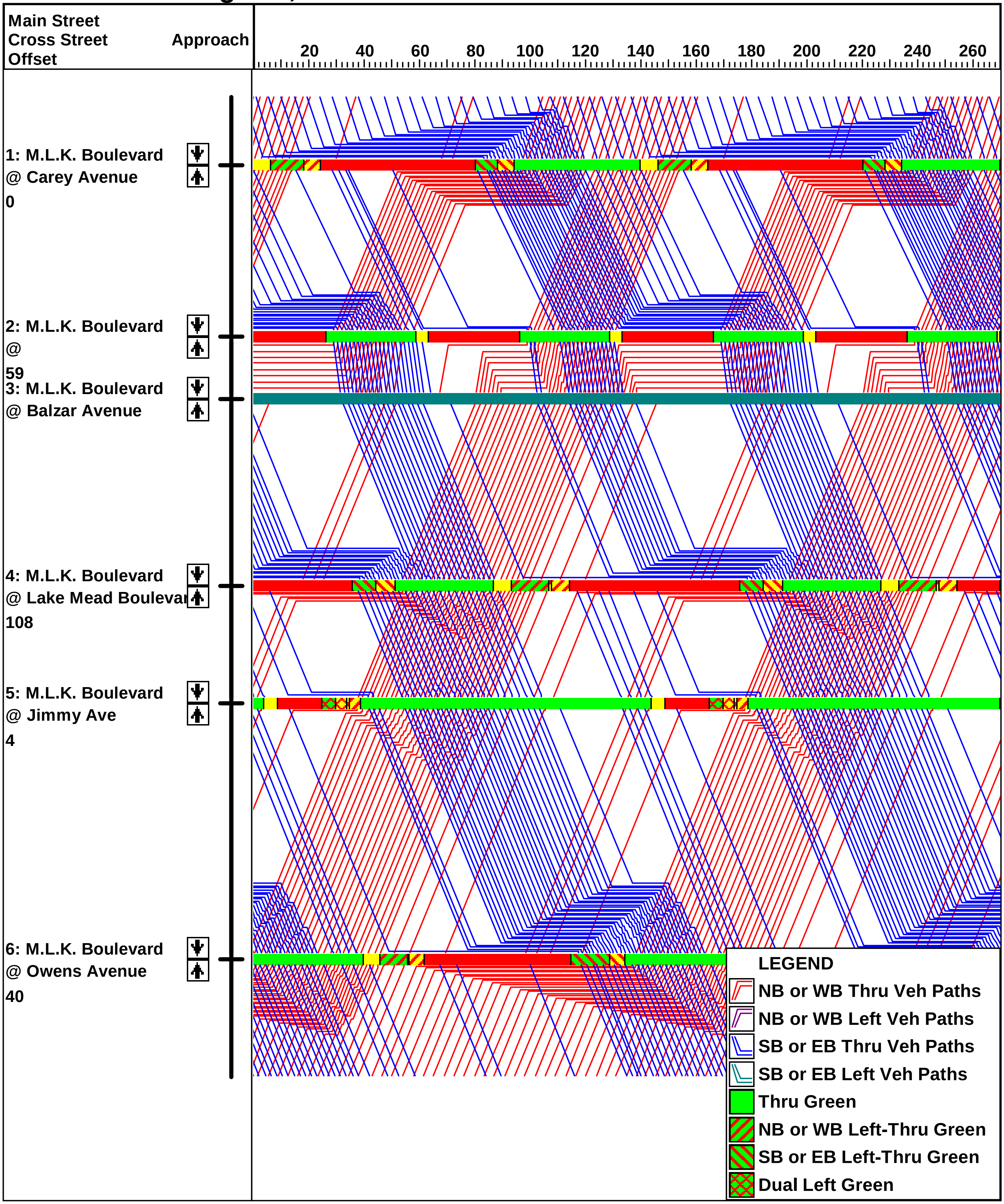


PM-25 2-Stage

Time-Space Diagram - M.L.K. Boulevard

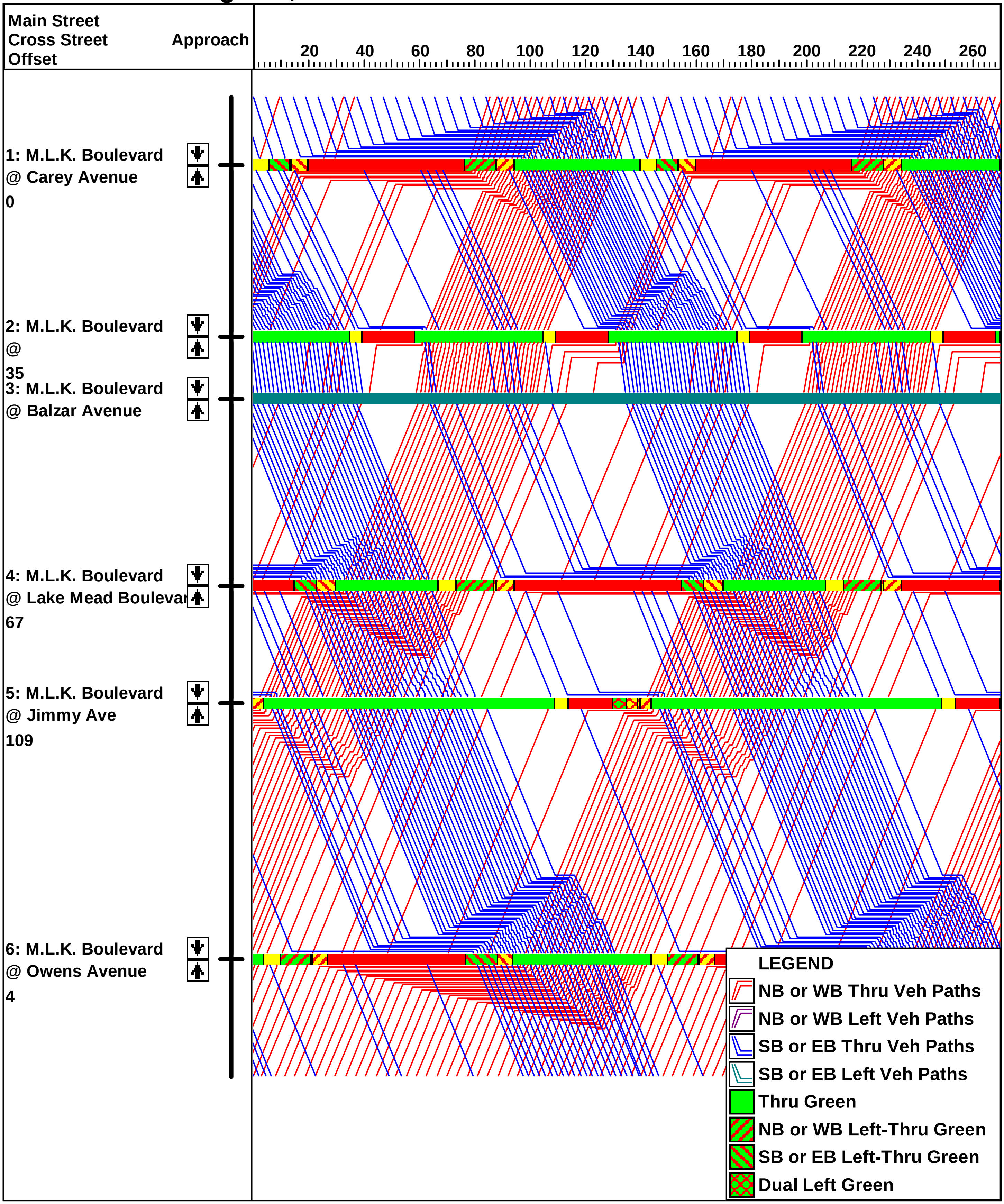
Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



PM+0 1-Stage

Time-Space Diagram - M.L.K. Boulevard

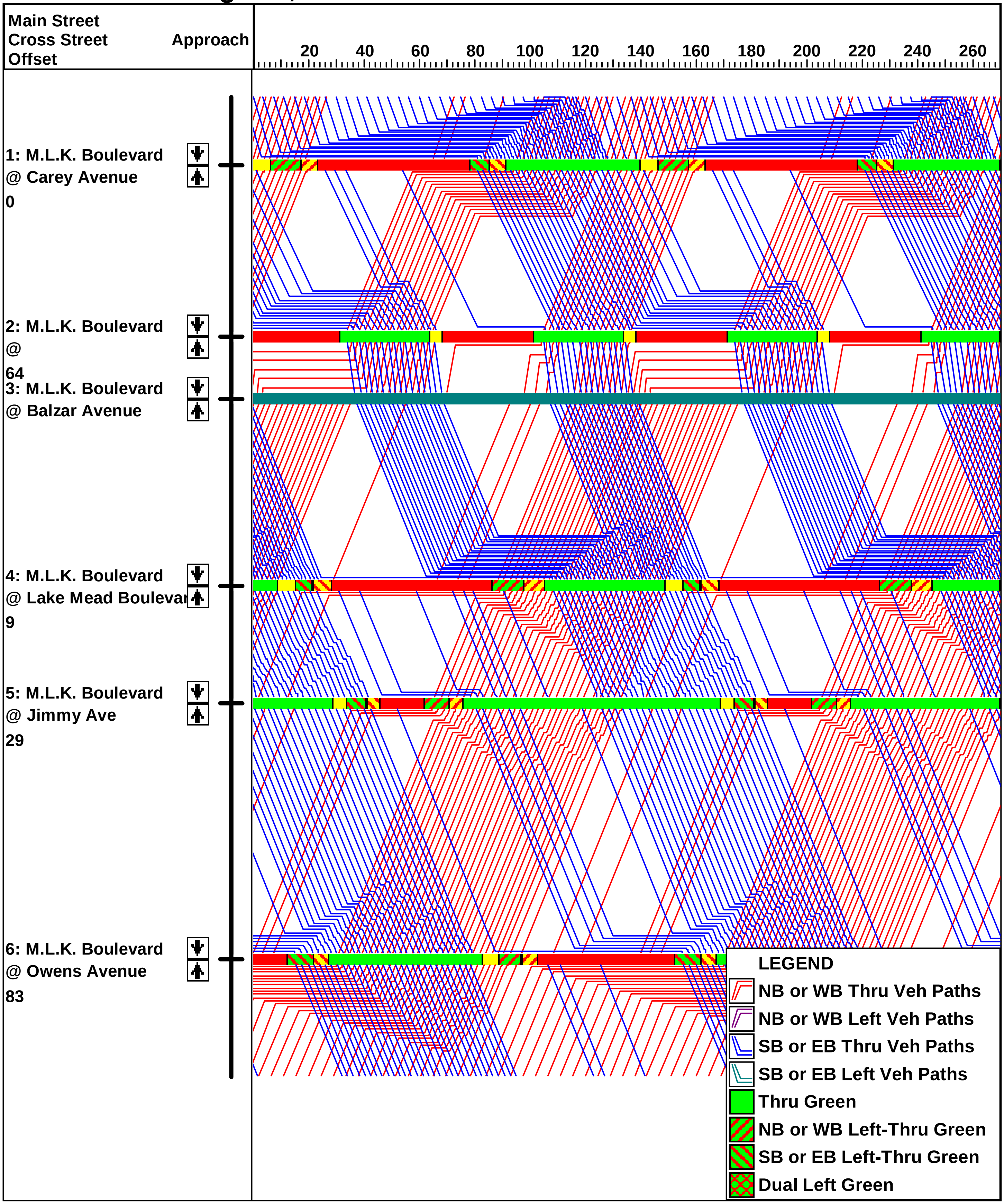
Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



PM+0 2-Stage

Time-Space Diagram - M.L.K. Boulevard

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



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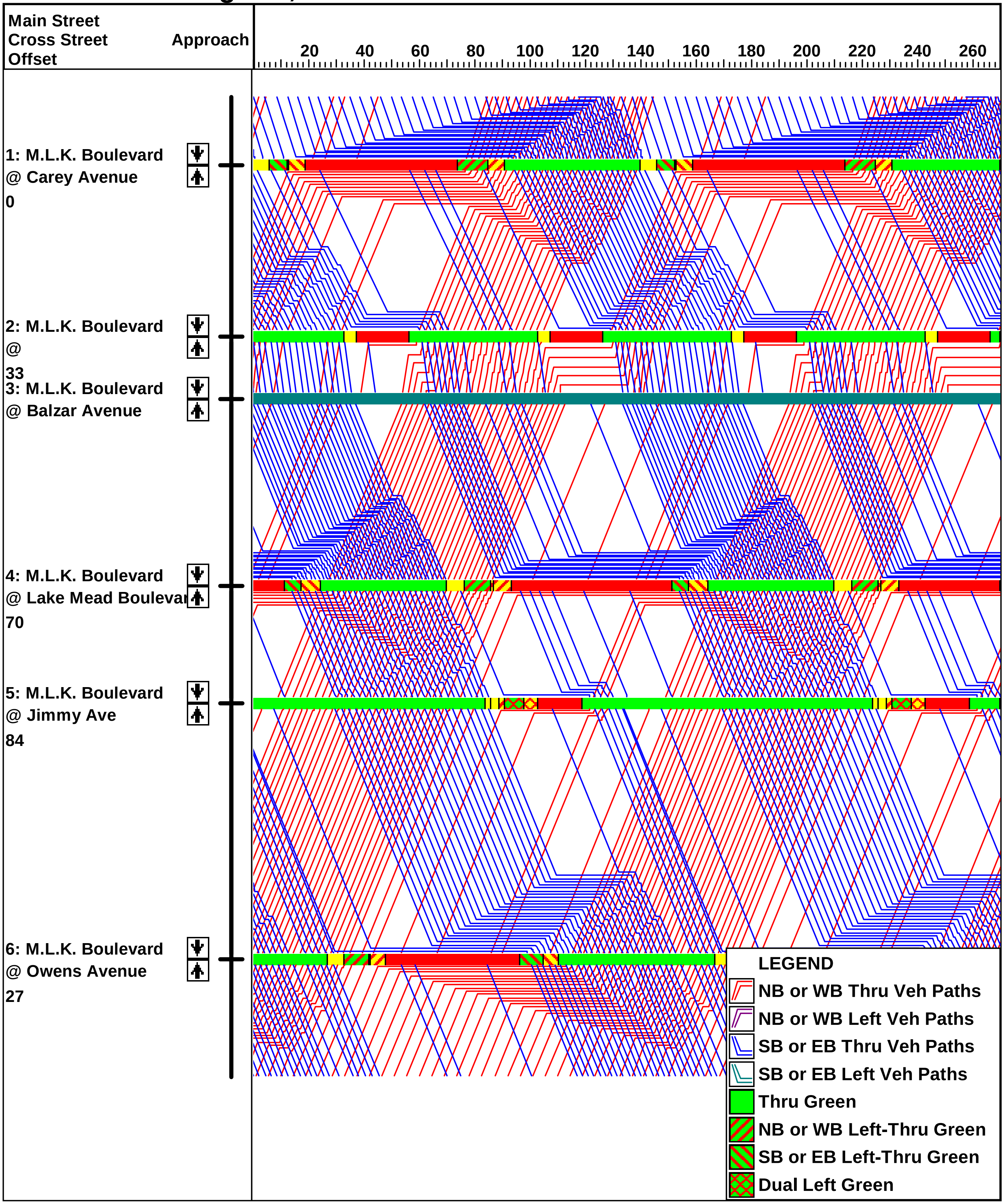
Time-Space Diagram - M.L.K. Boulevard

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



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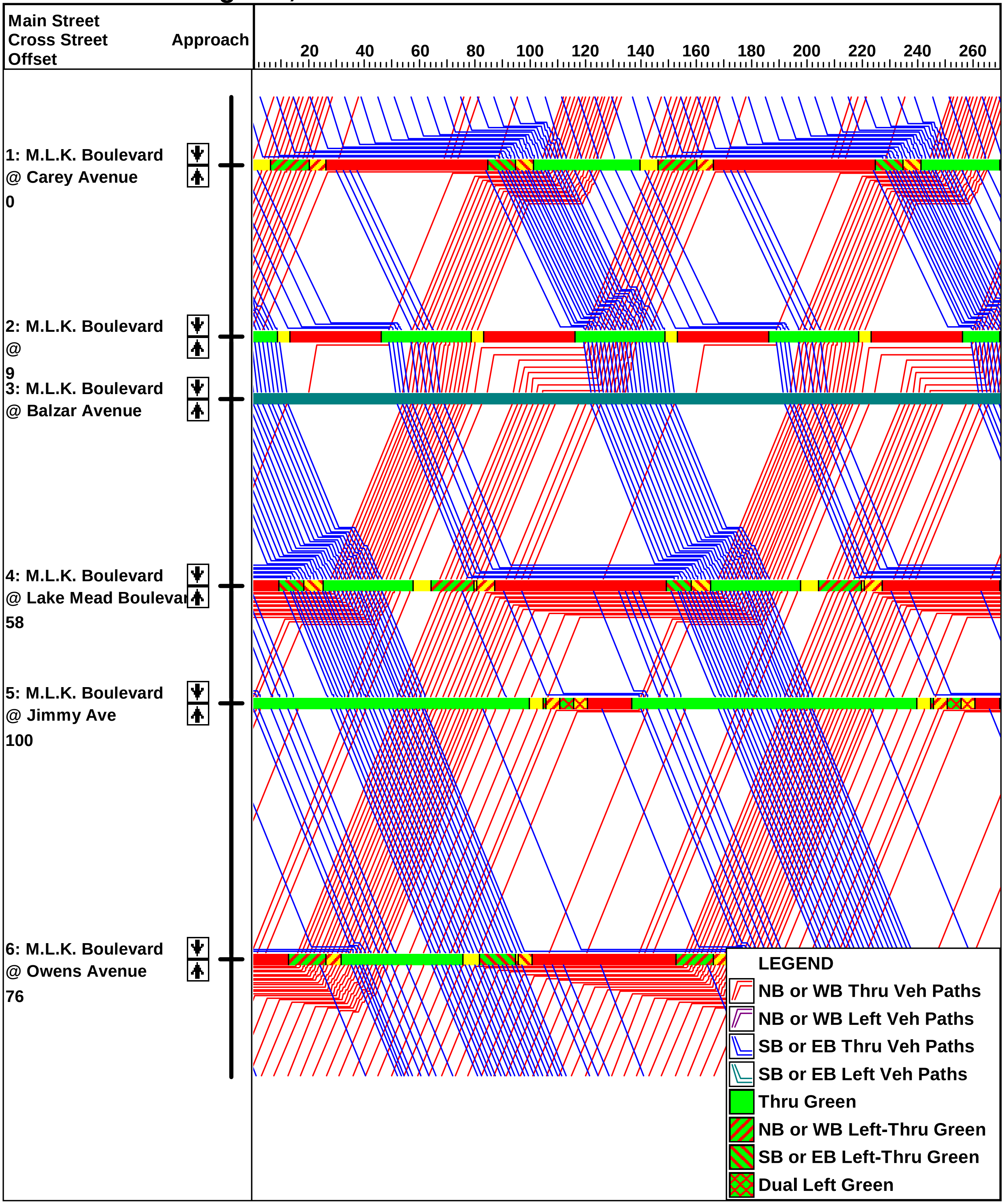
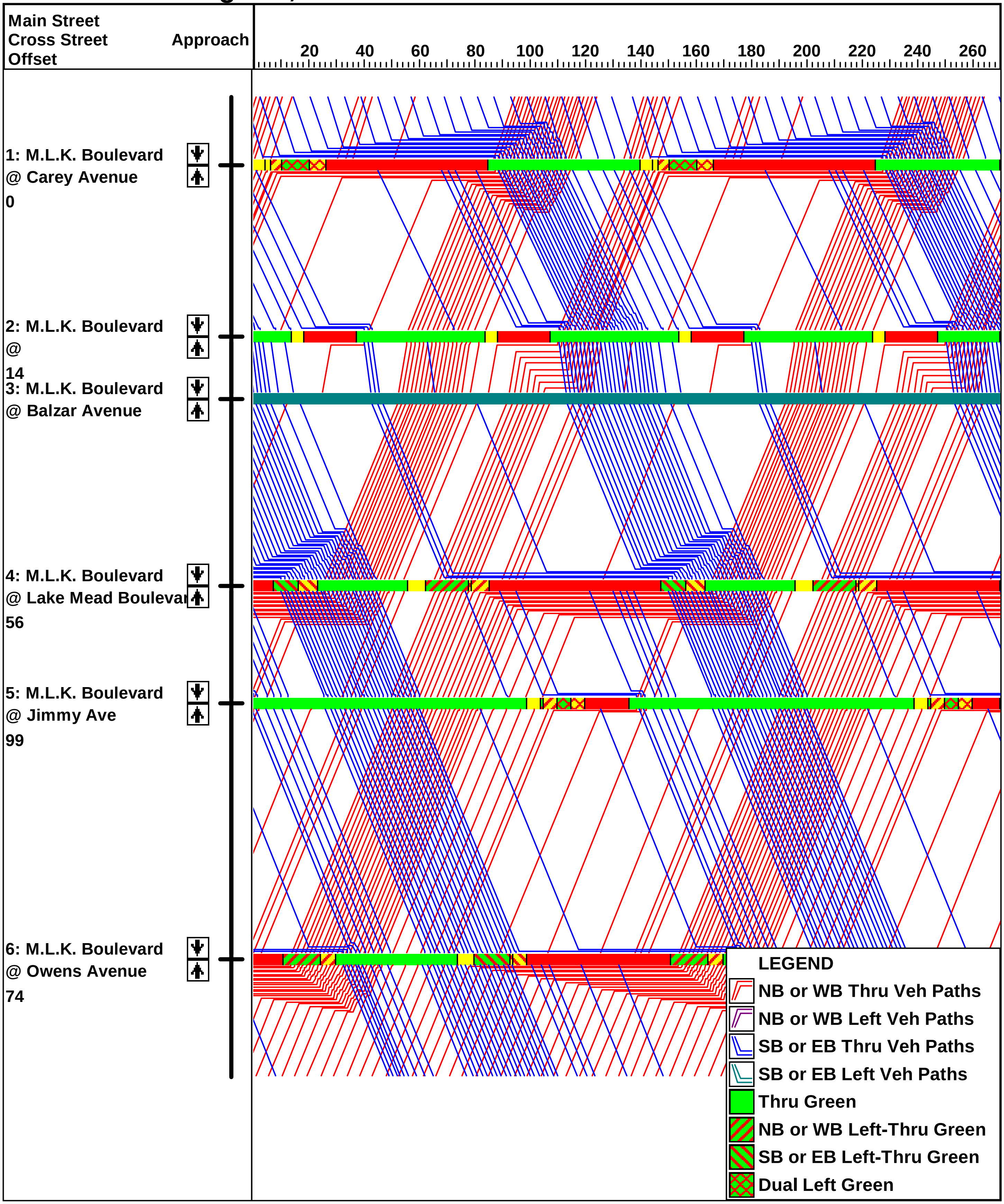
Time-Space Diagram - M.L.K. Boulevard
Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



PM-25 1-Stage

Time-Space Diagram - M.L.K. Boulevard

Traffic Flow Diagram, 90th Percentile Flow and Green Times 08/23/2023



PM-25 2-Stage

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