THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Product 0-7048-1
TxDOT PROJECT NUMBER 0-7048

Developing Countermeasures to Decrease Pedestrian Deaths: Guidebook

Kara Kockelman, Ph.D.
Kenneth A. Perrine
Natalia Zuniga-Garcia, Ph.D.
Maximillian Pleason
Maxwell Bernhardt
Mashrur Rahman
Jooyong Lee, Ph.D.
Alex Karner, Ph.D.

TxDOT Project 0-7048: Identify Risk Factors that Lead to Increase in Fatal Pedestrian Crashes and Develop Countermeasures to Reverse Trend

April 2022; Published August 2022

http://library.ctr.utexas.edu/ctr-publications/0-7048-P1.pdf

Performing Organization:
Center for Transportation Research
The University of Texas at Austin
3925 W. Braker Lane, 4th Floor
Austin, Texas 78759

Sponsoring Organization:
Texas Department of Transportation
Research and Technology Implementation Division
125 E. 11th St.
Austin, Texas 78701

Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Table of Contents

Introduction

Despite being the oldest and most environmentally friendly form of transportation, walking is becoming increasingly risky in the United States. While the total walk-miles traveled (WMT) is estimated to have risen 16% (BTS, 2019) between 2009 and 2017, the number of (reported) pedestrian deaths rose 46% (GHSA, 2020). Texas averaged 1.14 pedestrian deaths per 100,000 residents in 2019 (GHSA, 2020), which is 26% higher than the US average of 0.90.

Transportation planners and policymakers can cost-effectively reduce crash risks by implementing countermeasures with benefit-cost ratios (BCRs) over 1.0. Thoughtful benefit-cost analyses (BCAs) leverage a variety of relevant land use, infrastructure, traffic, and crash data and site-specific evaluations. BCA methods can differ significantly between those that focus on intersections and those that focus on (longer) road segments or corridors. Between 2010 and 2020, the number of intersection crashes doubled in both Texas and the City of Austin, while associated midblock segment crashes rose 30% and 75%, respectively (Zuniga-Garcia et al., 2021). Since vehicle speeds tend to be faster between intersections, mid-block pedestrian fatalities outnumber intersection deaths by more than 3 to 1.

Many resources exist to help in making roads safer and reducing all kinds of crashes. For example, the FHWA's (2018b) *Transportation Safety Planning and the Zero Deaths Vision: A Guide for Metropolitan Planning Organizations and Local Communities* provides references to key information for municipal planning organizations and local communities to understand the safety planning process and develop their own local or regional safety plan. The FHWA's (2009) *Primer on Safety Performance Measures for the Transportation Planning Process* identifies, selects, and applies safety performance measures as a part of the transportation planning process. And the FHWA's (2018a) *Guidebook on Identification of High Pedestrian Crash Locations* uses a data-driven approach to identify vulnerable locations. TxDOT maintains its own *Highway Safety Improvement Program Manual* (TxDOT, 2015) and AASHTO's (2014) *Highway Safety Manual* provides long series of equations for estimating crash counts by type and by type of roadway facility. However, the authors of this document perceive a need for a concise guidebook that presents an end-to-end methodology for selecting and justifying pedestrian crash countermeasures.

This guidebook is designed to enable practitioners at all levels of government to select the most cost-effective pedestrian-safety treatments for a wide variety of Texas contexts and reverse the rise in pedestrian deaths on Texas roadways. It provides a framework for prioritizing problematic intersections and corridors, analyzing the impact of relevant treatments (as cataloged in Appendix A) and identifying the resulting benefit-cost ratio and expected reduction in crashes. It incorporates research efforts conducted within the TxDOT Research and Technology Implementation Project 0-7048 (Kockelman et al., 2021) that surveyed practices from federal and other state agencies, mathematically analyzed contributing factors to crashes, and established the groundwork for the strategies described within this guidebook.

Figure 1 on the next page walks through a quick overview of strategies for reversing the trend. However, when going more in-depth, the process can be broken down to six major steps that are covered in the following sections. These include:

1. Finding an intersection or corridor of interest
2. Accessing relevant data sources
3. Identifying helpful variables
4. Identifying treatments
5. Visualizing data
6. Calculating benefit-cost ratios

With data, treatment plans, and benefit-cost ratios in hand, the practitioner will be well equipped to request necessary resources, establish partnerships and collaborations, and put plans into motion for implementing safety treatments that are proven to significantly reduce the chance for future injuries and fatalities.

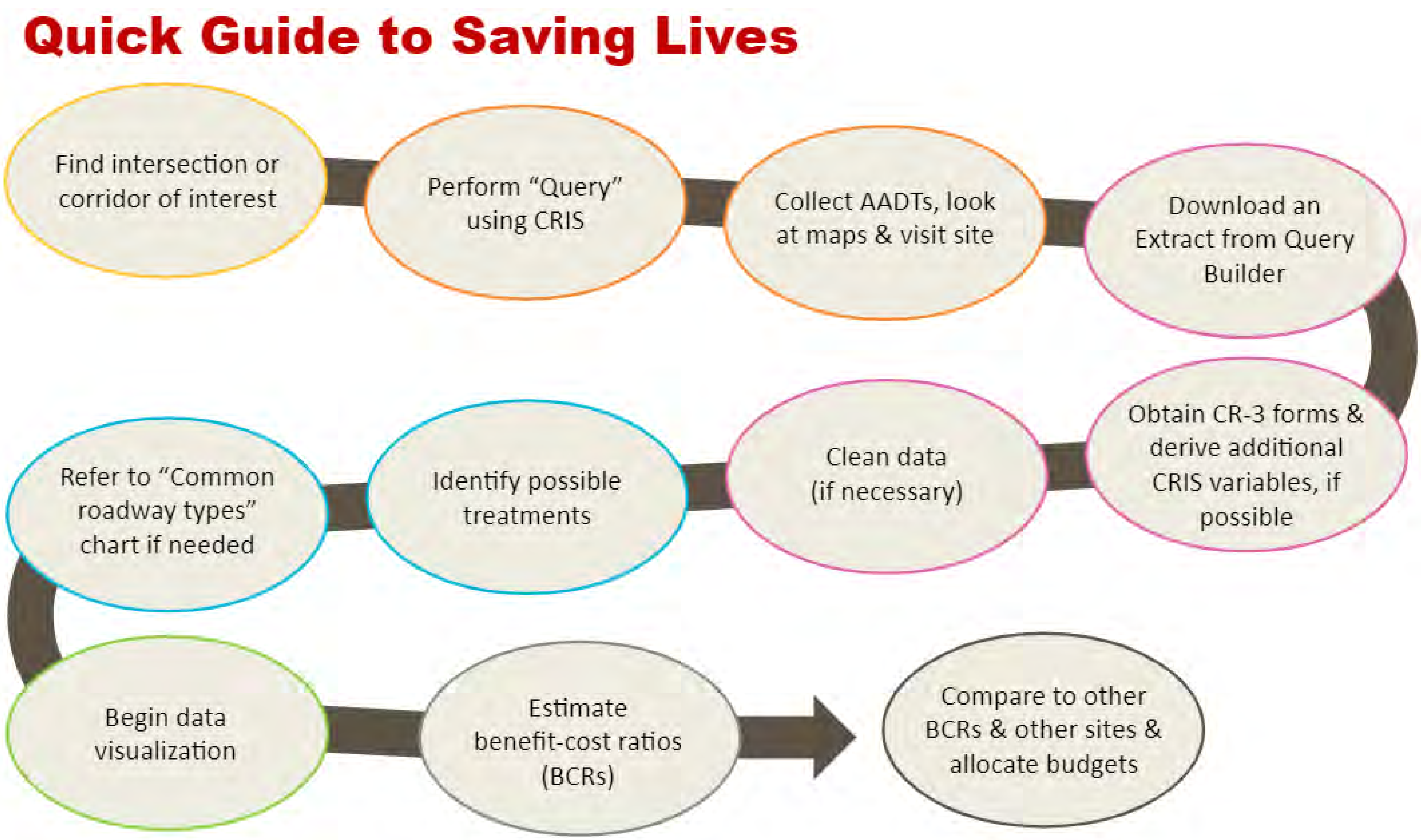

Figure 1. A Quick Guide to Saving Lives. This guide breaks down implementing pedestrian-safety treatments into approximately 10 steps, covering everything from how to select a location of interest to calculating BCRs.

1 Find an Intersection or Corridor of Interest

We present two strategies for choosing an intersection or corridor for further analysis:

A. The first involves establishing criteria to score locations across Texas according to crash severity, and then clustering together adjacent roadway segments and intersections to arrive at distinct corridors that cover crash-prone areas. These corridors can then be scored and ranked according to the process described in the full report (Kockelman et al., 2021). A ranked list of the 100 most crash-prone corridors in Texas is provided in the corresponding data set (https://utexas.box.com/v/ctr-pedcrash-0-7048). Figure 2 shows a section of highly ranked corridors within the Austin area. This strategy is amenable to urban centers, where intersections are closely spaced and pedestrian activity is high.

B. The second involves bypassing the aforementioned ranking strategy and giving attention to intersections or corridors that already receive significant public interest. This naturally allows for factors unique to a locality to be appropriately considered. Examples include problem areas that appear frequently in the news, or high-crash intersections visited by children or the elderly.

Whether the facility ranks high on a statewide scale or is of special interest at a local level, the same approach for performing a BCA using treatment strategies described in this guidebook can be followed.

Figure 2. Corridors among the Texas "top 100" within the central Austin area.

2 Access Relevant Data Sources

Once an intersection or corridor is chosen for analysis, the next step is to collect the data. A list and explanation of key data sources that may be leveraged are given in this section and Section 3. The best place to start collecting data for a specific pedestrian safety improvement project is the TxDOT CRIS database. This section will walk through how to obtain information from this database and provide a starting point for research.

2.1 What Is CRIS?

Data filed in the TxDOT CRIS (Crash Records Information System) database is accessible through the CRIS Query system (https://cris.dot.state.tx.us/public/Query/app/home) and available to the public. These data come from fields found on CR-3 crash report forms, codified within a database. They provide a means for querying several crash characteristics, such as cause of crash, injury severity, and number of vehicles and persons involved, which can be used directly in benefit-cost calculations. However, crash narratives and personally identifiable information are not provided in this public database. The website provides an online interface to perform queries, view locations on a map, and select attributes. It is also possible to download entire years' worth of data for all of Texas as "extracts" (see TxDOT, 2021) and analyze them in a separate system. This database is a good starting point to help in discovering "hot spots" and focusing efforts to manually request individual CR-3 crash record forms.

CR-3 forms provided by TxDOT are records filed by law enforcement officers who handle traffic crash scenes. An example is shown in Figure 3. CR-3 forms contain firsthand, historic narratives, making them an invaluable resource in understanding the more nuanced causes of a crash. However, because of the sensitive nature of personally identifiable information contained within CR-3 forms, access to these forms is restricted to personnel who can justify a need for access.

Since the total number of records at any location may be numerous, and the process of manually downloading hundreds of CR-3 forms is tedious, it is important to first identify and filter down to crashes that involve pedestrians. These may be individually retrieved from TxDOT by a unique identifier given to every record, or by intersection name. More information on using the TxDOT CRIS can be found on their website (https://www.txdot.gov/inside-txdot/division/traffic/law-enforcement/crash-records.html).

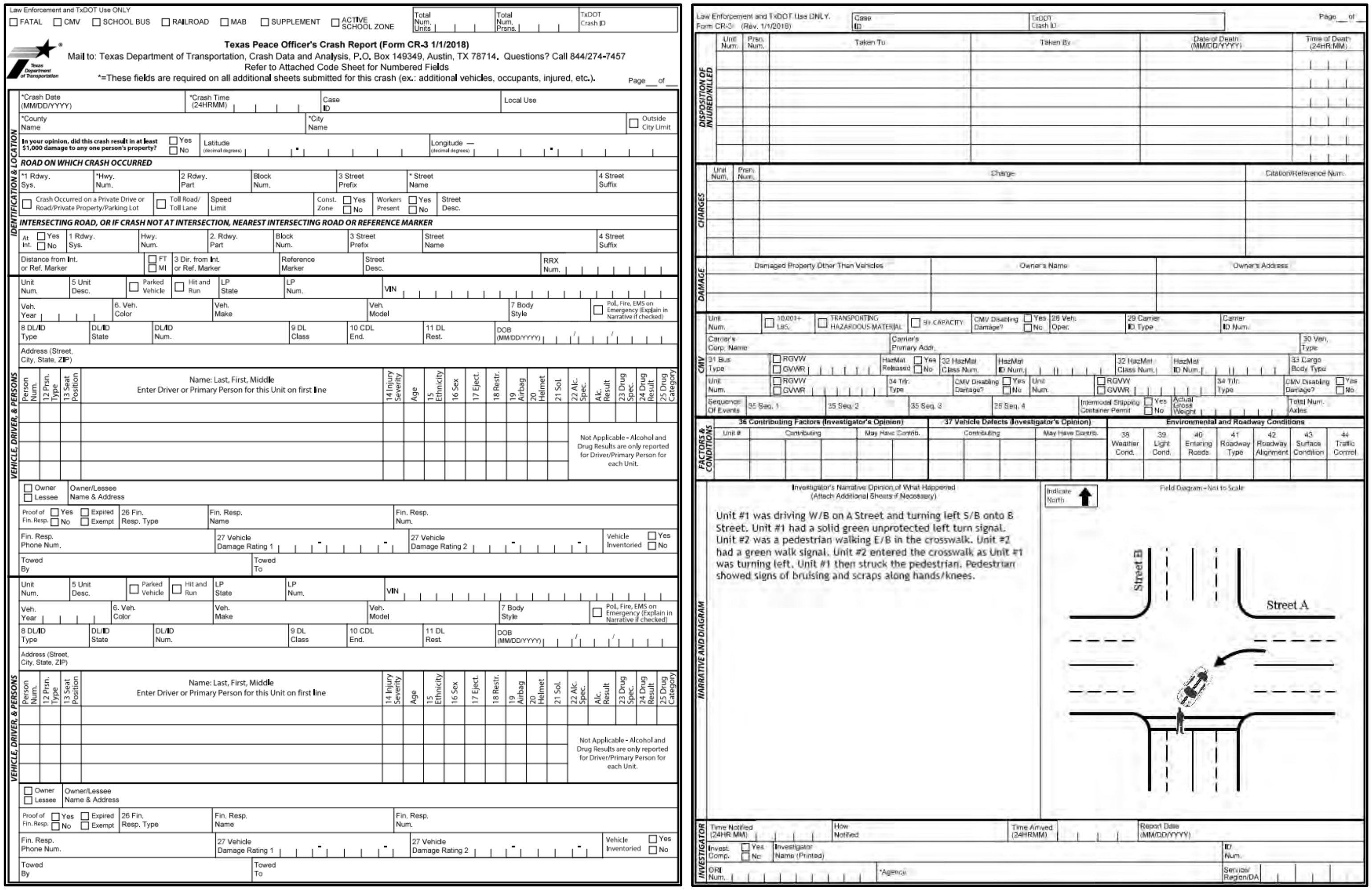

Figure 3. Example CR-3 document. Note the field labeled "Narrative and Diagram" alongside the bottom half of the righthand page. Reading the Investigator's Narrative and Field Diagram can provide critical insight to the cause of a crash.

2.2 Creating a Query and Extract

This section now looks at the web-based query interface for retrieving public CRIS data from the database. On the homepage, select "Create a new Query using the Query Builder." Then select "I want to find all Crashes that meet a certain set of criteria." Next, select the years to retrieve from the database. Note that TxDOT only keeps the last 10 years of records. However, this typically provides an adequate number of records for analyzing treatment strategies. Given the rarity of pedestrian crashes, the authors of this guide suggest using the full time range of available data to maximize the number of results; attention should also be given to understanding an intersection or corridor's history of prior safety improvements. On the Crash Location page, use either the default search method or interactive map as indicated in Figure 4.

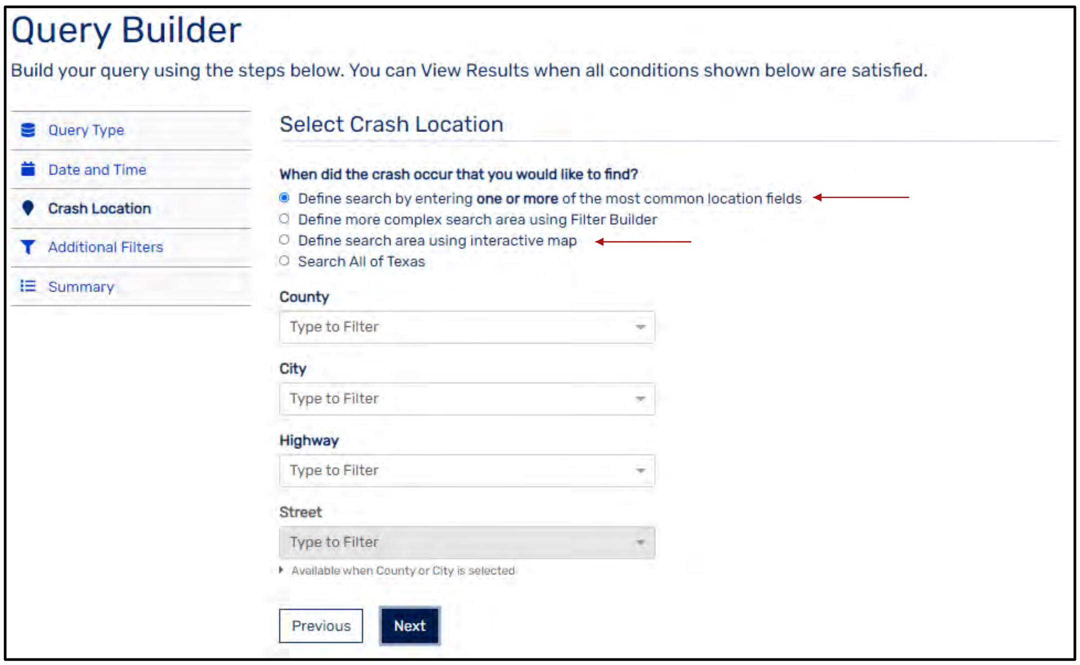

Figure 4. CRIS Query website.

If looking at a specific intersection, the authors of this guide suggest using the interactive map, shown in Figure 5. First, find the desired intersection on the map. Then select "Draw" and, under Selection Mode, "Point." Due to the small variations in how crashes are pinned on the map, set the buffer between 50 and 150 feet. Then click "Save Location." This range will capture all the crashes that occurred at the intersection as well as some nearby, possibly relevant crashes.

If looking at a corridor, use the "Segment" or "Polygon" tool. Using the segment tool, select the beginning and then the end of the corridor with a 50 to 150 feet buffer. Using the polygon tool, draw a polygon around the area and double-click to complete the shape. Click "Save Location" to finish.

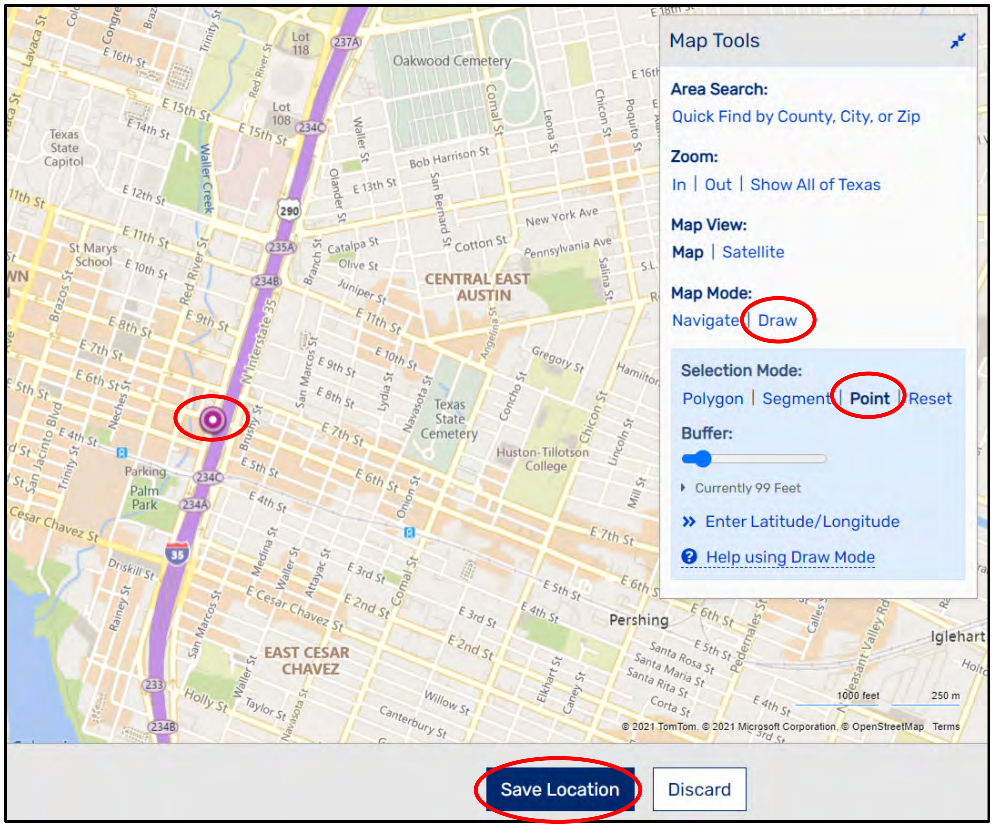

Figure 5. CRIS Query interactive map.

Once the search criteria are set, click "View Results." From here, the query results can be displayed on a map, in a pie or bar chart, in a table, or in an attribute list. To create an extract, select "Create an Attribute Table." On the attribute table page, select the columns of interest. Then click "Export CVS." This will export the query results as a CVS file, which can be manipulated in a separate program, such as GIS software or Microsoft Excel.

Section 3 includes information on which columns are typically helpful. Briefly, pedestrian crashes can be identified by selecting columns "Unit Description" or "Person Type." Non-pedestrian crashes can then be filtered out using a separate system.

2.3 Other Resources

Online mapping services, such as Google Maps and Google Earth, can show a map of roads and features within the area of interest. These can include transit stops, nearby schools, and even business names. Some services also provide satellite imagery that can be helpful for viewing roadway channelization (lane positions), sidewalk positions, possible pedestrian flows, positions of nearby schools and hospitals, and nearby business accesses that can influence vehicle and pedestrian flow.

The TxDOT Roadway Inventory (interactive online map and query tool accessible at https://gis-txdot.opendata.arcgis.com/datasets/txdot-roadway-inventory, shown in Figure 6) can provide additional information such as estimated daily vehicle counts, speed limit, lane count, shoulder width, median type, and in some cases information about the type of pavement. TxDOT also provides all Roadway Inventory maps for each year as a download that can be imported into GIS software; these are found at https://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html.

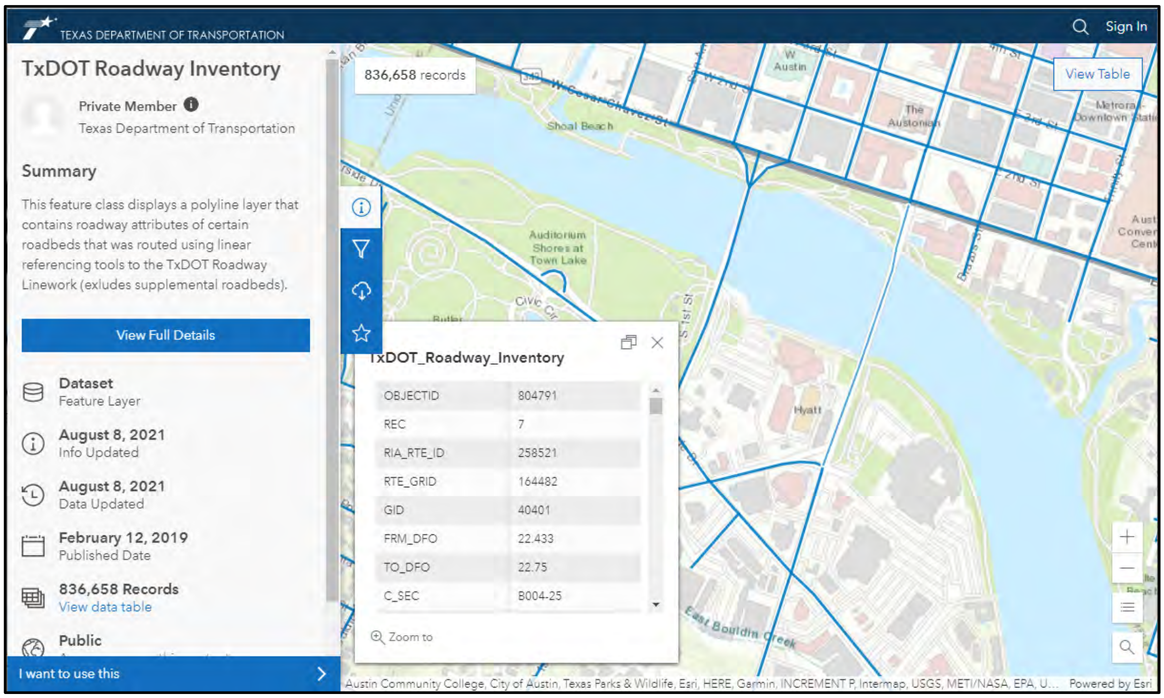

Figure 6. TxDOT Roadway Inventory online user interface.

Use site visits to locations to observe characteristics of traffic and pedestrian movements, and to visually investigate potential causes for future crashes. While databases can be good tools for methodically organizing quantitative information, a site visit can reveal additional insight that can't be captured in a database.

2.4 What Constitutes a Pedestrian-Related Crash?

The accurate determination of a *pedestrian-related* crash requires looking at several variables within CR-3 forms and the CRIS database. These can readily show how severely pedestrians are injured. It is up to the practitioner to determine whether additional crash records that document both injuries to vehicle occupants and "near misses" to pedestrians should also be included in an analysis.

Briefly, CRIS is organized as follows:

- For each crash, there are one or more *units* in the crash. These include vehicles and individual pedestrians.
- For each unit, there is one or more *persons*. These include identifying information tied to passengers in vehicles or lone pedestrians.

For more information, the authors encourage attending a free CR-3 training, offered on a frequent basis by TxDOT, which adds significant insight on how CRIS data are organized and how fields should properly be interpreted. Appendix C in the full report (Kockelman et al., 2021) offers additional highlights.

The authors identified several criteria to determine if a crash is a pedestrian-related crash. *One or more* of these must be true for the crash to be considered pedestrian-related:

- One or more units are identified as a pedestrian
- One or more persons are identified as a pedestrian
- The "harmful event" of a crash is a pedestrian injury
- The "other factor" involves a swerve or deceleration because of a pedestrian

Once practitioners have determined the scope of the project and compiled a list of related crashes or crash IDs, they can begin collecting and organizing the CRIS variables and other details for each crash record. For assistance in identifying crashes that are specifically pedestrian-related, a collection of crash identifiers for the last decade has been made available at https://utexas.box.com/v/ctr-pedcrash-0-7048 (file "ped_crash_data_simple_c.csv").

3 Identifying Helpful Variables

Practitioners are likely to find that the most informative data sources are the restricted CR-3 forms available in the TxDOT CRIS system, as well as the public CRIS database. The number of fields contained within CR-3 forms and those transcribed to the database are numerous. All should be scrutinized for the following reasons:

- Despite the hard-working efforts of officers who fill out CR-3 forms at crash sites, errors do exist in street names, details about crash locations and causes, and semantics of how certain fields are entered, and can also occur when TxDOT transcribes CR-3 information to the database.
- Many fields lack consistent data, as they may have been left blank on the original CR-3 forms.
- All aspects of crash details may not be apparent in the quantitative scheme enforced by the CR-3 fields and equivalent database encodings.

3.1 CRIS Variables

Despite these caveats, CR-3 forms and the CRIS database contain a wealth of information that is instrumental for finding the best treatments for crash-prone locations. Table 1 lists noteworthy fields that exemplify what is found in the database.

Table 1. Helpful CRIS Variables

Field	Description
At Intersection Flag	Signifies whether the crash occurs at an intersection or driveway.
Contributing Factors	Reporting officer's opinion on factors that led to the crash.
Crash Date	Date of crash.
Crash Severity	Describes severity of crash using KABCO scale.
Crash Time	Time of crash reported as 0 to 2400.
Day of Week	Day of the week.
Intersecting Street Name	Name of intersecting street (if applicable).
Light Condition	Describes the lighting around the area at the time of the crash (e.g., daylight, dark)

Field	Description
Private Drive Flag	States if crash occurred at a private drive (e.g., parking lot, driveway).
Street Name	Name of the primary street.
Weather Condition	Describes weather condition on numbered scale (1: clear, 2: cloudy, 3: rain).
Unit Description	Describes unit as motor vehicle or pedestrian.
Vehicle Travel Direction	Describes in what direction the vehicle was traveling right before crash. Not filled for pedestrian units.

Further information on these and other potentially useful fields may be found in the "Standard File Extract Specification" (TxDOT, 2021). Many fields are derived from CR-3 forms, but many also come from TxDOT personnel's interpretations from the narrative, as well as features of the surrounding roadways. It is important to again note that the database does not contain the narrative text, nor diagrams that the reporting officer may have drawn on the CR-3 form. This is one reason why the database can act as a screening tool to determine which CR-3 forms need to be queried and downloaded. Notably, fully reviewing the more intimate details of each crash within CR-3 forms can be a time-intensive process, especially for the more problematic corridors.

3.2 Derived CRIS Variables

Using the wide variety of CRIS variables available is an excellent way to start identifying common patterns in pedestrian-car crashes for a corridor or intersection. However, practitioners can use the process of leveraging the CR-3 narrative, diagram, and other data sources to create a set of "derived CRIS variables" that can also be extremely insightful. A list of derived variables used by this guidebook's authors can be found in Table 2 along with the notation used. Notation and details are highly flexible and should be adjusted to the comfort and needs of the practitioner.

Table 2. Derived CRIS Variables with Suggested Notation

Variables	Notation
Crosswalk ID	0: null; N: north; S: south; E: east; W: west. NE, SE, SW, NW used for intersections with >4 crosswalks or to add clarity.

Variables	Notation
Vehicle Bound	Indicates vehicle direction before crash. N: north; S: south; W: west; E: east. Notation such as NW can be used to add clarity (e.g., vehicle was headed W, turned right (R) and struck a pedestrian).
Vehicle Direction	0: null; L: left turn; R: right turn; S: straight through intersection
Pedestrian RoW	Y: pedestrian had right-of-way; N: pedestrian did not have right-of-way; U: unknown right-of-way; 0: null
Lane_#	CTL: center turning lane; 1: innermost lane; 2: second innermost lane; 3: third innermost lane; etc.

The "Crosswalk ID" variable is useful for labeling specific crosswalks (or lack thereof) at an intersection as potentially problematic. Decreasing the scale of a treatment to a portion of the intersection can lower the cost, increasing the benefit-cost ratio.

The "Pedestrian RoW" (right of way) variable is useful for identifying if treatments should focus on drivers or pedestrians. A location where vehicles tend to fail to yield RoW may benefit different countermeasure strategies than a location where pedestrians tend to fail to yield RoW.

The "Vehicle Bound" and "Vehicle Direction" variables can provide similar insights to the "Crosswalk ID" variable in narrowing the application of a treatment. These variables are especially helpful in identifying problematic left and right turns at an intersection.

3.3 Discrepancies in the Data

As previously mentioned, CR-3 forms are filled out mostly by police officers and transcribed into CRIS by TxDOT employees and as such are subject to human error and subjectivity. If practitioners have direct access to CR-3 forms for manual review, reinterpretation of specific variables can be justified. It is up to practitioners to use their best judgement and note any discrepancies in the data to identify useful countermeasures.

One common discrepancy is the "at intersection" variable. In pedestrian-car crashes, this problem is most prevalent in border cases where the pedestrian was struck by a vehicle just outside the intersection or by a car turning into a private drive, such as a parking lot. Reclassifying a crash to be at intersection is appropriate when it can be reasonably justified.

Further insight on possible discrepancies and proper interpretations of data can be gained by attending the TxDOT CR-3 training. Key insights the authors have gained from this training are listed in Appendix C of the full report (Kockelman et al., 2021).

4 Identify Treatments

Once an intersection or corridor has been identified, crash records obtained, and a query extracted, it is time to begin identifying treatments (countermeasures) to apply to the area. This guide focuses on engineering solutions such as hybrid beacons, pedestrian leading intervals, and speed reductions. However, other types of countermeasures, such as education and community outreach, can be equally valid.

An extensive, but non-exhaustive, list of over 70 countermeasures can be found in *Appendix A: Treatments by Category*. Treatments are arranged into broad categories such as roadway treatments, traffic calming treatments, pedestrian-specific treatments, and education. Applicable treatments also appear in the TxDOT *Highway Safety Improvement Program Guidelines* (TxDOT, 2021) (https://ftp.txdot.gov/pub/txdot-info/trf/hsip/hsip-guidance.pdf).

Beyond that, other agencies have worked diligently to reverse the trend in pedestrian crashes, providing well-supported resources. For example, the Federal Highway Administration (FHWA) provides a collection of countermeasures and strategies proven to be effective in reducing roadway fatalities and serious injuries. (https://safety.fhwa.dot.gov/provencountermeasures/, shown in Figure 7).

Figure 7. FHWA pedestrian-related Proven Safety Countermeasures (FHWA, 2021).

4.1 Treatment Coverage

Not all treatments are created equal. Different treatments will “cover” different types of crashes. Only injuries covered by a treatment can be used to calculate the benefit-cost ratio for that treatment. A leading pedestrian interval does not help to prevent crashes caused by high speeds. Similarly, a lower speed limit likely does not help to prevent crashes related to left turns. Understanding and tracking the cause of a crash is critical to identifying potential treatments. Ultimately, it is up to practitioners to determine which crashes are covered. Likewise, the physical context of the location may determine a treatment's appropriateness. An area with heavy nightlife may lend itself to different strategies than an area close to a major K–12 school. Care should also be taken to ensure that a proposed treatment does not induce more risk for additional pedestrian-related crashes. For example, a new bus shelter placed midblock in an area already seeing heavy jaywalking activity could encourage more jaywalking, unless other treatments are put in place to deter that behavior.

4.2 Manipulating Treatments

Sometimes, the delay cost of a treatment may be prohibitive. Even a 1-second delay can push the total cost of a treatment into millions of dollars on a busy road. Thus, finding creative ways to minimize the impact of a treatment can be a deciding factor in whether it is implemented. For example, a treatment that is only in effect for a portion of the day only affects a portion of drivers, reducing the total cost of the treatment.

Specifically, implementing a pedestrian leading interval only at night or on weekends can drastically reduce the delay-cost associated with the treatment. If most of the crashes at an intersection occur at night, trimming the treatment can give a boost to the treatment's final benefit-cost ratio (BCR). However, note that this will also reduce the coverage of the treatment and any historic crashes that occurred during the day cannot be used to calculate benefits.

4.3 Organizing the Data

The authors of this guide suggest tracking data and information on crashes in data manipulation software, such as Microsoft Excel. The CRIS query extract is an easy way to begin since the CVS file can be imported as a starting point for analysis. Remove the excess rows (1–9) at the top of the sheet to create a functional table. This table can then be further manipulated to remove non-pedestrian-related crashes from the data set. Given the cyclical nature of identifying treatments, practitioners will likely add variables from the CRIS to their data set over time. Creating an automated system to remove non-pedestrian-related crashes also allows practitioners to avoid time required for manually recleaning new extracts. Figure 8 displays an example of a query extract once all the non-pedestrian-related crashes have been removed. Note that the extract lists every unit of a crash separately, meaning information attached to motor vehicle units could be lost if cleaning is not performed carefully.

	A	B	C	D	E	F
1	Crash ID	Crash Date	Crash Severity	Crash Time	Weather Condition	Unit Description
2	12261013	7/26/2011	C - POSSIBLE INJURY	1906	1 - CLEAR	1 - MOTOR VEHICLE
3	12261013	7/26/2011	C - POSSIBLE INJURY	1906	1 - CLEAR	4 - PEDESTRIAN
4	12686805	5/6/2012	A - SUSPECTED SERIOUS INJURY	230	3 - RAIN	1 - MOTOR VEHICLE
5	12686805	5/6/2012	A - SUSPECTED SERIOUS INJURY	230	3 - RAIN	4 - PEDESTRIAN
6	13046549	11/30/2012	A - SUSPECTED SERIOUS INJURY	2339	1 - CLEAR	1 - MOTOR VEHICLE
7	13046549	11/30/2012	A - SUSPECTED SERIOUS INJURY	2339	1 - CLEAR	4 - PEDESTRIAN
8	13754073	12/29/2013	B - SUSPECTED MINOR INJURY	45	1 - CLEAR	1 - MOTOR VEHICLE
9	13754073	12/29/2013	B - SUSPECTED MINOR INJURY	45	1 - CLEAR	4 - PEDESTRIAN
10	13797090	4/10/2014	A - SUSPECTED SERIOUS INJURY	948	1 - CLEAR	1 - MOTOR VEHICLE
11	13797090	4/10/2014	A - SUSPECTED SERIOUS INJURY	948	1 - CLEAR	3 - PEDALCYCLIST
12	13803064	4/13/2014	C - POSSIBLE INJURY	2106	1 - CLEAR	1 - MOTOR VEHICLE
13	13803064	4/13/2014	C - POSSIBLE INJURY	2106	1 - CLEAR	4 - PEDESTRIAN
14	14133310	11/2/2014	A - SUSPECTED SERIOUS INJURY	2244	1 - CLEAR	1 - MOTOR VEHICLE
15	14133310	11/2/2014	A - SUSPECTED SERIOUS INJURY	2244	1 - CLEAR	4 - PEDESTRIAN
16	14347356	3/17/2015	A - SUSPECTED SERIOUS INJURY	2217	2 - CLOUDY	1 - MOTOR VEHICLE
17	14347356	3/17/2015	A - SUSPECTED SERIOUS INJURY	2217	2 - CLOUDY	4 - PEDESTRIAN
18	14610455	8/21/2015	C - POSSIBLE INJURY	1	1 - CLEAR	1 - MOTOR VEHICLE
19	14610455	8/21/2015	C - POSSIBLE INJURY	1	1 - CLEAR	4 - PEDESTRIAN

Figure 8. Example query extract excluding non-pedestrian related crashes.

If CR-3 forms are available, practitioners can add columns for derived CRIS variables. Remember that information for derived CRIS variables comes from reading the narratives found in CR-3 forms and only available with permission from TxDOT. Practitioners can complete the data set by reviewing each CR-3 form and transcribing the information to the data set.

4.4 Common Types of Corridors

Although every road and intersection is unique, many share sets of common characteristics related to their physical characteristics, the types of crashes that occur on them, and the treatments typically considered. Two main categories of corridors are identified here: *downtown corridors* and *"stroads."* Note that these categories are not exhaustive and are strictly mentioned to cover the most common use cases.

4.4.1 Downtown Corridors

The first broad category of corridors is downtown corridors, or those that exist in a central business district. These corridors can be one-way with 2–4 lanes, with average midblock speeds of approximately 30 mph. They also may feature high levels of pedestrian activity and have pedestrian crossings at every intersection. However, block widths can vary drastically (between 400 and 1,000 feet), meaning crossings may not be frequent. Examples of downtown corridors include Congress Avenue (Austin), Fannin Street (Houston), and Milam Street (Houston).

The most common type of crash on these corridors is overwhelmingly skewed towards vehicles failing to yield right-of-way, typically on turning movements. The other most common type of crash occurs when pedestrians attempt to cross against a Do Not Cross signal. These crashes reflect the high number of points of conflict between pedestrians and vehicles during signal cycles. Treatments for downtown corridors typically center around separating pedestrians and vehicles, decreasing the number of points of conflict. They include leading pedestrian intervals, dedicated pedestrian intervals, and implementing “no right on red” at intersections. Implementing traffic calming, such as narrower lanes and sidewalk décor, can also be beneficial.

4.4.2 “Stroads”

The second category of roadways is the “stroad,” a term growing in popularity among urban designers to describe roadways that mix the physical characteristics of a road with that of a street. In this context, a road, such as an arterial, is designed to maximize the movement of vehicles. Roads have wider lanes and higher speeds than streets. A street, on the other hand, can be considered a destination that attracts pedestrian activity. They are designed to facilitate commerce and community. Figure 9 further describes the different characteristics of a street and a road. Some examples of stroads around Texas are South Congress Avenue in Austin, Westheimer Road in Houston, and Zarzamora Street in San Antonio. Of the top 10 deadliest corridors in Texas, 6 can be classified as stroads.

The most common types of crashes that occur on stroads are pedestrians attempting to cross midblock, pedestrians crossing against a Do Not Cross signal, and vehicles failing to yield right-of-way during turns. These crashes reflect a lack of pedestrian infrastructure and lack of drivers’ awareness of the presence of pedestrians. Treatments for stroads typically include, but are not limited to, additional controlled pedestrian crossings (hybrid beacons, crosswalks at intersections), road redesign (replacing center turning lanes with medians, road diets), and removing curb cuts (parking lot entrances). However, note that these treatments typically have lower benefit-cost ratios due to their negative impact on traffic flow.

Figure 9. How to turn a stroad into a street or road. Courtesy of Strong Towns (https://www.strongtowns.org/journal/2018/2/15/how-to-turn-a-stroad-into-a-street-or-a-road).

5 Visualize Data

Visualizing crash data plays two important roles in the process of implementing pedestrian crash countermeasures. First, it assists in the identification of appropriate treatments. Even after all of the data for a particular corridor or intersection has been analyzed, there still may be ambiguity in understanding which treatments are best implemented. Having a variety of ways to visualize and reinterpret the data can be vital to breaking through creative walls.

The second role of data visualization is to help construct an argument to convince an audience (the public, transportation agency, etc.) that the selected treatment is appropriate, functional, and cost-effective. Each proposed treatment may have immediately perceived benefits and drawbacks that must be effectively clarified. Even the best idea is worthless if it is not effectively communicated to the group that makes the final decision. Coincidentally, this is also the task engineers may struggle with the most, making it deserving of extra attention.

5.1 Visualizing Corridors

It can be difficult to identify treatments for corridors because each corridor typically hosts both common and unique characteristics. A straightforward way to visualize both corridors and intersections is to take a screenshot from Google Earth and edit it in PowerPoint or Google Slides. GIS software may also provide helpful tools.

One technique for visualizing crashes along a corridor is to geospatially position them. Laying the crashes out according to the block number, nearest intersection, or GPS coordinates (if available) can allow obvious clusters of crashes to emerge. Sometimes, one or two problematic intersections may be creating the illusion of a larger corridor-wide problem. Visualizing crashes spatially can help identify these cases.

As seen in Figure 10, the majority of crashes along Tomball Parkway, in Houston, are clustered between Fallbrook Drive and Bammel Road. This may indicate that any corridor-wide countermeasures (such as a speed reduction) should only apply in this section of the corridor, possibly increasing the overall benefit-cost ratio. Note that in the case of Tomball Parkway, the data was visualized by grouping every crash to its nearest intersection. However, if a significant portion of the crashes did not occur at intersections, this type of visualization could be misleading.

Figure 10. Visualization of crashes along Tomball Parkway in Houston. Crashes that did not occur at intersections were grouped to the closest intersection. (Image obtained from Google Maps.)

5.2 Visualizing Intersections

Nearly all interventions will require the consideration of intersection-level countermeasures. Visualization of intersections can be time-intensive. Similar to corridors, intersection-level visualization can lead to countermeasures with higher benefit-cost ratios. There are a variety of ways to visualize crashes at intersections. One method, if appropriate, is to use the CR-3 data and narrative to track vehicles as they moved through the intersection immediately preceding a historic crash.

In Figure 11, information from CR-3 narratives was used to construct a visualization of the intersection of Congress Avenue and Cesar Chavez Street in Austin. Each arrow represents a vehicle going through the intersection immediately preceding a crash. Thicker arrows represent additional reports of vehicles making the same turn before a crash. Notice that four of the crashes occurred as a car made a left turn, and approximately three occurred during a right turn. This indicates that a pedestrian leading interval may help to prevent further crashes at the intersection. Note that other factors such as the time of day and the lighting of the intersection could also influence these crashes. However, these factors are not represented in the figure.

Visualizations can reveal key details on the causes of crashes and nature of treatments to consider. This only tells part of the story necessary to justify a treatment strategy. The other part, benefit-cost ratios (explained in depth in the next section), produces a quantitative measure that can make way for effective implementation.

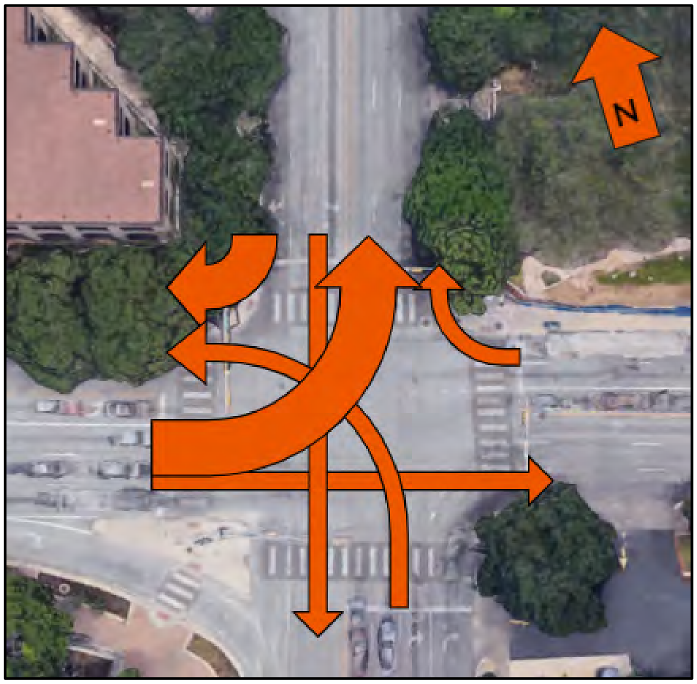

Figure 11. Visualization of pedestrian crashes at the intersection of Congress Avenue and Cesar Chavez Street in Austin. (Image obtained from Google Maps.)

6 Calculate Benefit-Cost Ratios

A benefit-cost ratio (BCR) is simply the ratio of a countermeasure's valued benefits to its costs for a given time frame (typically 10 to 20 years for roadway-infrastructure investments). Benefits are taken as the anticipated reduction in crash costs multiplied by the treatment's Crash Reduction Factor (CRF). The cost of a countermeasure is the sum of the implementation or construction cost and the delay cost to drivers (if applicable).

A BCR of 1 is required to show that a treatment will "break even," meaning that for every $1 invested, society saves or benefits by at least $1 in value. However, this does not mean that treatments with a BCR < 1 should not be considered! BCRs are conservative in nature, and if a community feels strongly about a specific treatment, that may provide evidence of benefits not accounted for in the BCR. For example, the aesthetic benefits of vegetated medians, roundabouts (instead of signals), extended sidewalks, and brick crosswalks are real but difficult to monetize. Similarly, the health care savings of stronger hearts and bodies from more walking and biking, and the peace of mind that comes with added safety for oneself and family members, due to wider sidewalks, lower vehicle speeds, and/or added bike lanes are meaningful, but difficult to quantify.

6.1 Primary Considerations

Calculating BCRs requires several inputs. Mainly, it requires the cost of implementation or construction, the crash modification factor (CMF) of the treatment, the value lost from previous crashes, the average annual daily traffic (ADT) of the road(s), and the average delay-hour cost per vehicle. For some treatment strategies, it may also be appropriate to include maintenance costs that are assessed over time. Since inputs to BCRs are generally estimates or projections, the BCR itself is a rough estimate. BCRs need not be precise, but their inputs should be justified.

Estimated costs of implementation for a variety of treatments and their CMFs can be found in *Appendix A: Treatments by Category*. Note that when calculating a BCR, benefits are multiplied by the treatment's CRF. The CRF of a treatment is equal to 1 minus the CMF. CMFs for many treatments can also be found here: http://www.cmfclearinghouse.org/. In addition, TxDOT maintains CMFs for a selection of relevant safety improvements in the Highway Safety Improvement Program website (at https://www.txdot.gov/inside-txdot/forms-publications/publications/highway-safety.html).

Crash costs were derived using TxDOT's *Highway Safety Improvement Program Manual* from 2020 (TxDOT, 2020). The average comprehensive cost in the KABCO system (adjusted for inflation to 2021) includes quality-of-life costs and lost productivity and can be found in Table 3. Note that this breakdown is based on the perspective of TxDOT. Practitioners may use discretion in judging whether it is appropriate to use the provided crash unit costs.

Table 3. Breakdown of crash severity ratings (TxDOT, 2020)

Crash Severity Type	Injury Type	Average Cost per Crash
K	Fatality/Fatalities within 30 days	$3,500,000
A	Suspected Serious Injury(ies)	$3,500,000
B	Suspected Minor Injury(ies)	$500,000
C	Possible Injury(ies)	$0
O	No Apparent Injury(ies)	$0
U	Unknown	$0

Vehicle delay costs can be incurred when treatments slow vehicular traffic. To reflect such costs, an average delay-hour cost of $14.14 per vehicle-hour is assumed here. This is close to what the United States Department of Transportation (2021) uses which is $15 per vehicle-hour. In treatments of a leading pedestrian interval, one might expect an average delay of 1 second per vehicle using that intersection (since most users' arrival times downstream will be unaffected, but some may lose an entire cycle by landing at a red light downstream). For a "no right turn on red" prohibition, vehicles about to turn right may lose an average of 10 seconds each. Pedestrian hybrid beacons may impose a 2-second average delay for each vehicle in the corridor (since most are unaffected, but those who stop at the start of the mid-block red may lose 30 seconds or more, depending on how they arrive at downstream signals and traffic conditions). Each setting differs, and practitioners should use local site-based details, professional experience, and other available resources to provide representative estimates.

A time-horizon of 10 years is recommended here to avoid the mathematics of discounting over a 20-year investment horizon, at a rate of 7 to 8 percent per year. A discount rate of 7.8% on a 20-year stream of constant benefits is the same as summing 10 years of those benefits. In other words, the crash savings over 20 years, to arrive as the equivalent benefits of a 10-year implementation (without discounting), or future delay costs across 20, are equivalent to the simple summation of a 10-year horizon. Most infrastructure projects (like street lighting, medians, and extended sidewalks) have lifetimes of 20 years. If the treatment (e.g., public information campaigns or high-visibility vest giveaways) have much shorter lifetimes, then much shorter benefits (and/or cost) durations should be used.

Many pedestrian-safety treatments involve little to no delay costs for motorists. And some municipal transportation agencies will not consider delays to motorists in their BCRs, to help reflect the other benefits that come with such improvements (and the long-term biases in roadway design that some believe to benefit motorists). Regardless of personal positions, a second BCR can be calculated without using delay costs in order to offer decision-makers and the public another value for comparison in evaluating final treatment choices.

Other considerations can be applied based upon the discretion of the practitioner and the needs of the respective agency. Examples include:

- Under-reporting and under-recording of pedestrian crashes (which may cause BCRs to be biased low);
- costs of coordination and oversight by other agencies (like an affected railway or local utility provider);
- construction delays (including any major infrastructure change/treatment on existing facilities); and
- benefits (and costs) to the environment and wider world (like reductions in pollution and noise).

6.2 Steps to Calculate a BCR

1. Select a treatment. Find the implementation or construction cost, CMF, and delay per vehicle for the treatment. Find the ADT for the road or roads in the affected area. Assume a discount rate.
2. Multiply the sum of the ADTs by 365 days and 10 years to calculate the number of vehicles impacted over 10 years.
3. Multiply the number of vehicles by the delay per vehicle caused by the treatment. Divide by 3,600 seconds per hour to calculate the hours of delay over 10 years. If delay costs are not relevant or should not be considered, then set this to 0.
4. Multiply by the average delay-hour cost per vehicle (e.g., $14.14 per vehicle-hour) to estimate the total cost of delay from the considered treatment.
5. Sum the cost of delay with the cost of implementation or construction to estimate the long-term (10-year) total cost of the treatment.
6. Sum the crash costs from 10 years of previous, related crashes (or the expected crash costs of the coming 10 years, if that can be anticipated) and multiply by the CRF (or 1 minus the CMF) to calculate the total benefits.
7. Divide benefits by costs to find the BCR.

6.3 Other Considerations

Unfortunately, some benefits are difficult to measure, such as environmental benefits or mode shift from private cars to walking or bicycling induced by treatment strategies that encourage walkability. These benefits are left out of the calculations for the purposes of this section, but may be considered when evaluating BCRs for pedestrian safety at a more comprehensive level.

6.4 Examples

Below are 3 examples of calculated BCRs for intersections and corridors among the 50 highest-crash locations in Texas for pedestrians. These BCR calculations are written out in full, showing each step and mirroring the calculation logic used for the large-scale treatment recommendations.

1. Congress Avenue and Cesar Chavez Street – Austin
Treatment: 5-Second Pedestrian Leading Interval (1 second delay per vehicle, CMF: 0.85, Installation cost: $1750)
Costs:
Number of vehicles impacted = (ADT on Cesar Chavez (28,625) + ADT on Congress (15,785)) x 365 days in the year = 16,202,350 vehicles per year (162,023,500 in the 10-year period)
Total vehicle delay = 162,023,500 vehicles x 1 second = 162,023,500 seconds of delay overall; 162,023,500 vehicle delay-seconds / 3,600 seconds per hour = 45,007 hours of delay
$14.14 x 45,007 delay hours = $636,399 + $1,750 = $638,149 in total costs
Benefits:
7 Class B injuries ($500,000 x 7) + 1 Class A injury ($3,500,000) during 2010–2019 = $7,000,000 in crash costs
CRF = 1 – CMF = 1- 0.85 = 0.15
$7,000,000 x 0.15 = $1,050,000 in cost
BCR = $1,050,000 / $638,149 = 1.65
BCR (without delay costs) = $1,050,000 / $1,750 = 600

At this intersection, a large fraction of crashes was caused by drivers failing to yield right-of-way to pedestrians in the crosswalk. A pedestrian leading interval was deemed an appropriate treatment due to its coverage of these types of crashes. The treatment is believed to cover 7 non-incapacitating injuries and 1 incapacitating injury that occurred over the past 10 years. Other crashes may have occurred, but they were not covered by the treatment and are not included. Note that further consideration can be given to the time of day most of the historic pedestrian-related crashes occurred; at this location, most crashes occurred at night after the evening peak, allowing for the possibility of implementing the pedestrian leading interval only during off-peak hours to reduce delay costs.

2. Milam Street from McGowan Street to Alabama Street – Houston
Treatment: Road Diet (CMF: 0.71, Installation cost: $4,000 per mile, 0.6 miles long)
Cost of installation:

Dropping from 4 lanes to 3 lanes results in 25% decreased capacity. Current travel time through corridor = 4 minutes. Assuming 25% longer travel time after road diet, 5 minutes required. Each vehicle is delayed by an average of 60 seconds.

Number of vehicles impacted = ADT on Milam (14,530) x 365 days = 5,303,450 vehicles (53,034,500 in 10-year period)

Total vehicle delay: 53,034,500 vehicles x 60 seconds = 3,182,070,000 seconds of delay overall; 3,182,070,000 vehicle delay-seconds / 3,600 seconds per hour = 883,900 hours of delay

88,390 hours x $14.14 per vehicle delay-hour = $1,249,834 + $2,400 (cost of installation) = $1,252,234 in total costs

Benefits:

5 Class B injuries ($500,000 x 5) + 4 Class A injuries ($3,500,000 x 4) for 2010–2019 = $16,500,000

CRF = 1 – 0.77 = 0.23

$16,500,000 x 0.23 (CRF) = $3,795,000 in benefits

BCR = $3,795,000 / $1,252,234 = 3.03

BCR (without delay costs) = $3,795,000 / $2,400 = 1581

Since the proposed treatment affects traffic flow for a large number of vehicles, consideration for this strategy should include the comprehensive effects of reduced capacity, including revised routes that some drivers may take to avoid the added delay. This kind of road diet may induce more demand for alternative modes such as transit or bicycling. Such demand may be facilitated by repurposing the space on the roadway that was formerly used by general-purpose lanes.

3. Westheimer Road from Fondren Road to Chimney Rock Road – Houston

Treatment: Speed Limit Reductions – 10% decrease ($520 per new sign, 35 mph to 30 mph over 2.7 miles, CMF: 0.79)

Cost of installation: Estimate 20 signs x $520 = $10,400

Delay = (2.7 miles / 30 mph) – (2.7 miles / 35 mph) x 3600 seconds per hour = 46 seconds per vehicle

Number of vehicles impacted = ADT on Westheimer (15,211) x 365 days x 10 years = 55,520,150 vehicles

Total vehicle delay = 55,520,150 vehicles x 46 seconds = 2,553,927,000 seconds delay

2,553,927,000 vehicle delay-seconds / 3,600 seconds per hour = 709,424 hours of delay

709,424 hours x $14.14 per vehicle delay-hour = $10,031,257 + $1,350 (cost of installation) = $10,041,657 in total costs

Benefits:

14 Class K/A injuries ($3,500,000 x 14) + 24 Class B injuries ($500,000 x 24) for 2010–2019 = $61,000,000

CRF = 1 – 0.79 = 0.21

$61,000,000 x 0.21 (CRF) = $12,810,000 in benefits

BCR = $12,810,000 / $10,041,657 = 1.28

BCR (without delay costs) = $12,810,000 / $10,400 = 1,231

Drivers' actual speeds are a fraction of the change in posted speed limit. Some types of traffic control devices, such as radar or camera speed signs, may be effective in improving adherence (FHWA, 2021).

References

AASHTO (American Association of State Highway and Transportation Officials), 2014. Highway Safety Manual.

Arellano, Miguel, 2021. E-mail conversation regarding TxDOT Homelessness Efforts. January 3, 2021.

Bachman, S. L., Arbogast, H., Ruiz, P., Farag, M., Demeter, N. E., Upperman, J. S., & Burke, R. V., 2015. A school–hospital partnership increases knowledge of pedestrian and motor vehicle safety. Journal of community health, 40(6), 1057-1064.

BTS (Bureau of Transportation Statistics), 2019. National Transportation Statistics: U.S. Passenger-Miles. URL: https://www.bts.gov/content/us-passenger-miles (accessed Dec. 2021)

Bushell, M. A., Poole, B. W., Zegeer, C. V., & Rodriguez, D. A., 2013. Costs for pedestrian and bicyclist infrastructure improvements. University of North Carolina Highway Safety Research Center, University of North Carolina, Chapel Hill, 45.

Cantulupo, J., 2021. Email correspondence by Kara Kockelman with Texas Dept of Transportation Austin District Engineer, Joseph Cantulupo regarding pedestrian deaths.

Crash Modification Factors (CMFs) Clearinghouse, 2021. How to Develop and Use CMFs. Accessed on April 27, 2021 at: http://www.cmfclearinghouse.org/cmf_data.cfm

Davis, A., 2014. U.S. City Thinks Having Pedestrians Carry Flags Will Keep Them Safe. Wired, Conde Nast. Accessed at: https://www.wired.com/2014/06/bridgeport-pedestrian-flags/

FHWA (Federal Highway Administration), 2009. A Primer on Safety Performance Measures for the Transportation Planning Process, Report No. FHWA-HEP-09-043.

FHWA, 2018a. Guidebook on Identification of High Pedestrian Crash Locations, Report No. FHWA-HRT-17-106.

FHWA, 2018b. Transportation Safety Planning and the Zero Deaths Vision: A Guide for Metropolitan Planning Organizations and Local Communities. Report No. FHWA-SA-18-024.

FHWA, 2018c. Toolbox of Pedestrian Countermeasures and Their Potential Effectiveness (Report FHWA-SA-018-41). Federal Highway Administration, US Department of Transportation, Washington, DC.

FHWA, 2021. Proven Safety Countermeasures. URL: https://safety.fhwa.dot.gov/provencountermeasures/ (accessed Dec. 2021)

Fitzpatrick, K., Iragavarapu, V., Brewer, M., Lord, D., Hudson, J., Avelar, R., & Robertson, J., 2014. Characteristics of Texas Pedestrian Crashes and

Evaluation of Driver Yielding at Pedestrian Treatments. Texas A&M Transportation Institute, Texas A&M, 50.

GHSA (Governors Highway Safety Association), 2020. Pedestrian Traffic Deaths by State, Spotlight on Highway Safety.

Kockelman, Kara, Kenneth A. Perrine, Jooyong Lee, Maximillian Pleason, Natalia Zuniga-Garcia, Maxwell Bernhardt, Mashrur Rahman, and Alex Karner, 2021. Identifying Risk Factors that Lead to Increase in Fatal Pedestrian Crashes and Developing Countermeasures to Reverse the Trend, Report No. 0-7048-1.

Madsen, J., Andersen, T., & Lahrmann, H., 2013. Safety effects of permanent running lights for bicycles: A controlled experiment. Accident Analysis and Prevention 50: 820-9.

Muennig, P., Epstein, M., Guohua, L., & DiMaggio, C., 2014. The Cost-Effectiveness of New York City's Safe Routes to School Program. American Journal of Public Health 104(7): 1294-1299.

Nowacki, Lauren, 2022. How Much Does a Tiny Home Cost? Rocket Homes, Rocket Homes. Accessed at: https://www.rockethomes.com/blog/home-buying/tiny-house#:~:text=The%20average%20cost%20of%20a,frills%20you%20want%20to%20include.

TxDOT (Texas Department of Transportation), 2021. Highway Safety Improvement Program Guidelines. URL: https://ftp.txdot.gov/pub/txdot-info/trf/hsip/hsip-guidance.pdf (accessed Aug. 2022)

TxDOT, 2021. 2010 and Greater, Standard File Extract Specification. URL: https://www.txdot.gov/government/enforcement/data-access.html (accessed Nov. 2021)

USDOT (United States Department of Transportation), 2021. Benefit-Cost Analysis Guidance for Discretionary Grant Programs. URL: https://www.transportation.gov/office-policy/transportation-policy/benefit-cost-analysis-guidance-discretionary-grant-programs-0 (accessed Nov. 2021)

Zuniga-Garcia, Natalia, Kenneth A. Perrine, and Kara Kockelman, 2021. Analysis of Pedestrian Crashes at Intersection and Midblock Segment Levels in Texas. Presented at the 101st Annual Meeting of the Transportation Research Board, and under review for publication in *Journal of Transport and Health*.

Appendix A: Treatments by Category

This non-exhaustive collection of common or noteworthy treatments has been gathered from a variety of sources as documented in the full report (Kockelman et al., 2021). Note that CMF values are merely a tool to assist in estimating BCRs. They're subject to conditions found at each unique treatment site, and should be used with engineering judgment.

Table A.1: Basic Roadway Treatments

	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Avg. CMF	Hi/Lo CMF
Basic curb and gutter[1]	108	$20	$21	$1.05/$120	Linear foot	0.89	
"Daylighting" left turns & crossing locations[1]	2	$300	$300	$50/$250	Each	0.75	0.52/1.49
Gateway signage (see examples)[1]	6	$15,350	$22,750	$5,000/$64,330	Sign + structure (each)	0.83	0.68/0.98
Narrowed curb radii[1]	12		$32,500	$15,000/$40,000	Per corner	0.81	
Pedestrian hybrid beacons[1]	9	$51,460	$57,560	$21,440/$128,660	Each	0.71	0.63/0.84
Prohibition of left turns[1]	6		$800		Per sign	0.28	0.23/0.36
Prohibition of right turn on red[1]	4		$800		Per sign	0.77	0.70/0.97
Crosswalk (Hi-vis; see citation for specs)[1]	4	$3,070	$2,540	$600/$5,710	Each	0.63	
Raised crosswalk[1]	6		$18,995	$7,110/$30,080	Each	0.64	0.55/0.7
Flashing beacon[2]	25	$5,170	$10,010	$360/$59,100	Each	0.85	
Rectangular red flashing beacon (RRFB)[2]	4	$14,160	$22,250	$4,520/$52,310	Each	0.53	
Raised median (controlled)[3]	9	$22,500		$15,000/$30,000	100 ft.	0.60	0.33/0.75
Raised center medians (uncontrolled)[1]	30	$6	$7.26	$1.86/$44	Square foot	0.93	0.61/1.94
Freeway fencing (both sides)[1]			$25	$1/$100	Linear foot	0.63	0.10/0.87

[1] CMF Clearinghouse, 2021
[2] Bushell et al., 2013
[3] FHWA, 2018c

	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Avg. CMF	Hi/Lo CMF
Advanced stop/yield sign[4]		$520	$570	$100/$1,150	Each	0.75	
Crosswalk sign[4]	23	$520	$570	$100/$1,150	Each	0.91	0.86/0.95
Narrow roadway from 4 lanes to 3 lanes[5]			$20,000	$12,500/$50,000	Per mile	0.71	

Table A.2: Traffic Calming Treatments

	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Speed humps[4]	14	$2,130	$2,640	$690/$6,860	Each	0.64	0.73/0.55
Speed limit reductions – 15% decrease[4]			$135		Each (sign)	0.89	0.83/0.95
Speed limit reductions – 10% decrease[4]			$135		Each (sign)	0.79	0.68/0.9
Speed limit reductions – 5% decrease[4]			$135		Each (sign)	0.705	0.56/0.85
Chicanes[4]	9	$8,050	$9,960	$2,140/$25,730	Each	0.69	0.64/0.75
Diverters[4]	6	$22,790	$26,040	$10,000/$51,460	Each	0.69	0.64/0.75
Curb extensions (bulb-outs)[4]		$10,150	$13,000	$1,070/$41,170	Each	0.75	0.51/1.07
Traffic circle[4]	14	$27,190	$85,370	$5,000/$523,080	Each	0.75	0.51/1.07
Road diet[6]	10		$40,000	$25,000/$100,000	Per mile	0.71	
Hardened left turns[7]	20	$2,500	$2,500	$2,000/$3,000	Each	0.65	

Table A.3: Pedestrian-Specific Treatments

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Streetlight (lighting ped area sufficiently)[8]	17	$3,600	$4,880	$310/$13,900	Each	0.44	0.19/0.69

4 CMF Clearinghouse, 2021
5 FHWA, 2018c
6 Fitzpatrick et al., 2014
7 https://www.autoblog.com/2020/04/12/iihs-left-turn-pedestrian/
8 CMF Clearinghouse, 2021

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
In-pavement lighting (flashing crosswalks)[8]	4	$18,250	$17,260	$6,480/$40,000	Complete system	0.71	
Pedestrian leading intervals[8]	4	$1,750	$1,750	$0/$3,500	Per signalized intersection	0.85	0.71/1.48
Crosswalk signage (for road users)[9]		$30	$30	$25/$35	Square foot	0.84	0.75/0.88
Bollards (at crossing points)[8]	42	$650	$730	$62/$4,130	Each	0.93	
Curb ramps (to crossings)[8]	74	$740	$810	$89/$3,600	Each	0.95	
Pedestrian refuge islands[8]	15	$9.80	$10	$2.28/$26	Square foot	0.44	0.25/0.76
Fence (general purpose)[8]	7	$120	$130	$17/$370	Linear foot	0.63	0.10/0.87
Pedestrian overpass (wooden)[10]	8	$122,610	$124,670	$91,010/$165,710	Each	0.63	0.10/0.87
Pedestrian overpass (steel)[8, 10]	5	$191,400	$206,290	$41,580/$653,840	Each	0.63	0.10/0.87
Pedestrian underpass[8, 10]		$120			Square foot	0.63	0.10/0.87
Sidewalk railings[8]	33	$95	$100	$7.20/$690	Linear foot	0.83	0.52/1.18
Access management improvements (esp. at commercial centers)[11]	3	$4,000	$4,000	$3,000/$5,000	Per driveway removed	0.50	
Full street closure (one city block)[8]				$500/$120,000	Per block	0.05	
Partial street closure (depends on treatment)[8]		$37,500		$10,290/$41,170	Per block	0.71	
Pedestrian detection – detector (actuate)[8]	14	$180	$390	$68/$1,330	Each	0.55	
Pedestrian detection - push button[8]	34	$230	$350	$61/$2,510	Each	0.83	
Audible pedestrian signal[8]	4	$810	$800	$550/$990	Each	0.72	
Increase crossing time[8]	10	$1,750			Per re-timing	0.49	
Countdown timers[8]	18	$600	$740	$190/$1,930	Each	0.48	0.3/0.75
Pedestrian signal (complete)[12]	70	$2,680	$3,260	$850/$13,410	Each	0.60	0.45/0.85
Traffic signal (new)[13]	25		$90,000	$80,000/$100,000	Each	0.44	0.50/1.48

9 http://www.trafficsign.us/signcost.html
10 Fitzpatrick et al., 2014
11 https://mobility.tamu.edu/mip/strategies-pdfs/system-modification/technical-summary/Access-Management-4-Pg.pdf
12 CMF Clearinghouse, 2021
13 https://ftp.txdot.gov/pub/txdot-info/pio/casbrochures/pub_signals.pdf

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Dedicated pedestrian interval[12]	4		$1,750	$0/$3,500	Per re-timing	0.41	0.16/0.49
Speed trailers[12]	6	$9,480	$9,510	$7,000/$12,410	Each	0.95	0.93/0.95

Table A.4: Street Furniture Treatments

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Street trees[12]	7	$460	$430	$54/$940	Each	0.82	
Bench[12]	17	$1,660	$1,550	$220/$5,750	Each	0.82	
Bus shelter[12]	4	$11,490	$11,560	$5,230/$41,850	Each	0.82	
Trash/recycling receptacle[12]	13	$1,330	$1,420	$310/$3,220	Each	0.82	

Table A.5: New Sidewalk Treatments

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Widen paved shoulder[12, 14]	4	$5.81	$5.56	$2.96/$7.65	Square foot	0.72	0.54/1.01
Asphalt sidewalk[12]	11	$16	$35	$6.02/$150	Linear foot	0.26	
Concrete sidewalk[12]	164	$27	$32	$2.09/$410	Linear foot	0.26	
Concrete sidewalk w/curb[12]	7	$170	$150	$23/$230	Linear foot	0.26	
Multi-use trail – paved[12, 14]	42	$261,000	$481,140	$64,470/$4,228,520	Mile	0.14	
Multi-use trail – unpaved[15, 16]	7	$83,870	$121,390	$29,520/$412,720	Mile	0.14	

[14] Fitzpatric et al., 2014
[15] CMF Clearinghouse, 2021
[16] Fitzpatrick et al., 2014

Table A.6: Education Treatments

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
"Be safe, be seen"[17]	1		$18,000		Campaign implementation	0.93	
Primary school training from local police department[18]	1		$18,000		Campaign implementation	0.90	
OOH advertising campaigns[19]	1		$18,000		Campaign implementation	0.93	
Anti-distracted-driving campaign[19]	1		$18,000		Campaign implementation	0.93	
Safe Routes to School – educational programs[20]	5		$10,298		Curriculum implementation	0.93	

Table A.7: Unhoused Persons-centric Treatments, Direct Outreach to Pedestrians

Treatment	N =	Cost (median)	Cost (average)	Cost (min/max)	Cost Unit (i.e., linear foot)	Average CMF	Hi/Lo CMF
Hi-visibility vests[21]	40	$12	$10	$4/$50	Each	0.85	
Tiny housing to decrease freeway camps[22]	5	$60,000	$45,000	$7,500/$150,000	Each	0.90	
Lights for pedestrians[23]	10	$20	$40	$7.50/$60	Lights + implementation	0.79	
Flags for pedestrian crossings[24]	3	$0.50 (unit)	$500 (total)	$50/$18,000	Total program cost	0.90	

17 Arellano, 2021
18 Bachman et al., 2015
19 Cantulupo, 2021
20 Muennig et al., 2014
21 https://www.homedepot.com/b/Safety-Equipment-Safety-Vests/N-5yc1vZc29h
22 Nowacki, 2021
23 Madsen et al., 2103
24 Davis, 2014