Appendix F. Roadway Safety Measures Toolbox Methodology

BART

Safe Trips to BART

Task 5 Roadway Safety Measures Toolbox Methodology

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| September 27, 2024

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Countermeasures Introduction

This report summarizes the process used for identifying roadway safety countermeasures to address the safety issues along the High Injury Network (HIN) identified within each BART station catchment area. Selecting the appropriate countermeasures requires an understanding of local travel behaviors, roadway design, and other environmental and contextual factors within the catchment areas.

Methodology Overview

To identify the appropriate countermeasures for BART station catchment areas, a toolbox of engineering interventions was developed based on best practices, Federal Highway Administration recommendations, and the safety findings from HIN analysis in Task 3, which is summarized in the following section.

Safety Analysis Key Findings

In Task 3, the research team analyzed roadway safety within the 48 non-airport station catchment areas and developed a high injury network (HIN) for those areas. For this analysis, the five counties in which BART provides service are classified as the BART region. BART's station catchment areas cover 14% of the BART region's roadway miles, but the BART HIN captured 24% of severe and fatal crashes in that same region, indicating a clear need to prioritize safety improvements in these areas (see Task 3 HIN findings). The safety analysis also revealed that pedestrians and motorcyclists are disproportionately likely to experience severe outcomes, followed by bicyclists, compared to motorists, and that injury severity is consistently higher around auto-oriented BART stations (see Figure 1). This finding is consistent with the industry understanding that more vulnerable road users are disproportionately impacted by traffic risk and safety countermeasures must therefore focus on protecting people outside of vehicles.

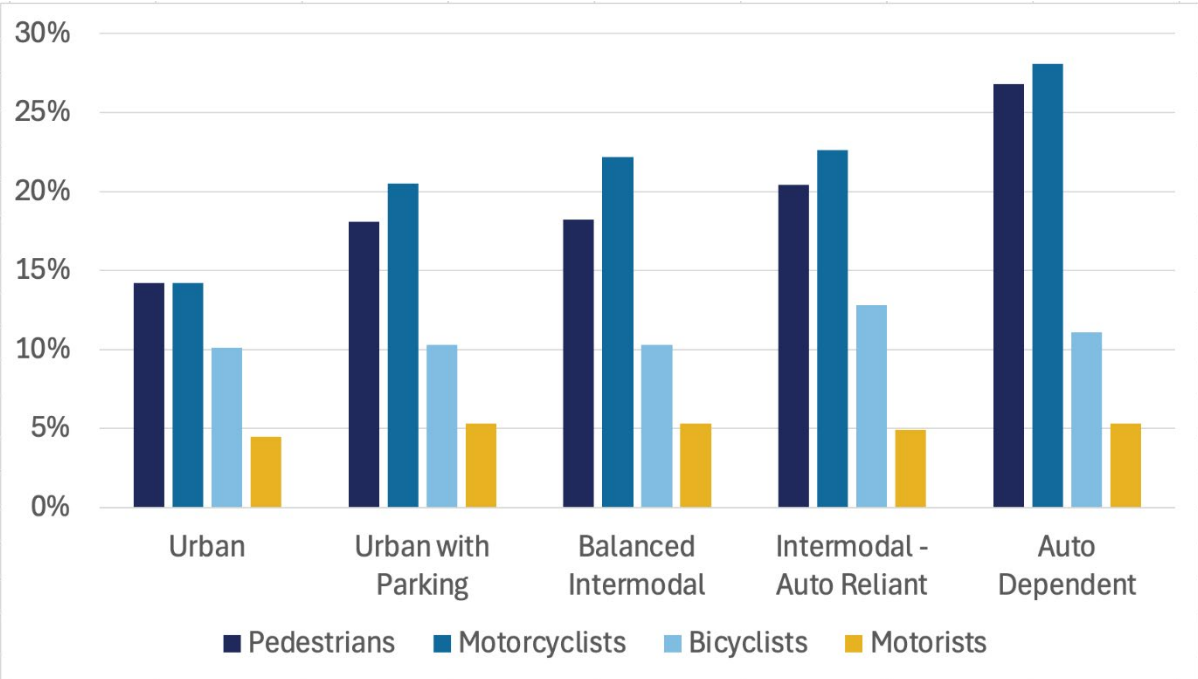

Figure 1 Percentage of Crashes Resulting in a Severe Outcome, by Mode and Station Type
Source: BART Safety Action Plan for Roadways Task 3 Safety Analysis Findings

The analysis found that safety patterns vary by station access typology. While the HIN capture rate (i.e., the number of fatal and severe collisions in the area that are on streets identified as part of the HIN) is *higher* in Urban station areas, crash severity is consistently *lower* in Urban station areas than in Auto Dependent and Intermodal - Auto Reliant station areas. The higher capture rate in Urban areas is due in part to road network density – in denser areas, crashes tend to be more concentrated on the more limited number of network miles. In more auto-oriented areas, crashes may be even more likely to be severe due to more prevalent factors that promote vehicle speed, including speed policy (reflected in posted speed limits) and roadway design.

However, crashes are also more dispersed throughout the network and therefore less likely to show up in an analysis tool like an HIN. As such, the HIN is an important tool to identify priority projects, but some investments may also be needed off the network in certain areas.

Risk factors differ somewhat by station type and each individual station with the station type. For example, posted speed limit and injury severity are known to be significantly related, but that relationship is less clear within each station access type in this analysis, which may reflect statutory speed limits in places like San Francisco. Since there is some variability in risk factors at stations of the same typology, the toolbox provides groupings of countermeasures by risk factors instead of station typology (See Table 5).

The nine major risk factors identified in the HIN analysis can generally be categorized into three categories:

- Modifiable Roadway Design & Operational Factors
  - Arterial classification
  - 4+ lanes
  - Posted speed greater than equal to 35 mph
  - Proximity to transit stops
- Crash Location Type Factors
  - Midblock Crossing
  - Signalized Intersection
  - Unsignalized Intersection
- Environmental Factors
  - Lighting

Modifiable Roadway Design & Operational Factors include design choices that prioritize vehicle traffic. For example, designers and municipalities choose how many lanes to build or stripe, how to classify the roadway, what the posted speed will be, and where to place transit infrastructure. These choices can either prioritize or compromise the safety of vulnerable road users.

Crash Location-Type Factors are contextual. For example, an intersection between roadways must exist; it will either be signalized or unsignalized, and each of these choices comes with safety implications that may be mitigated with mindful design and countermeasures. Unsignalized intersections include any intersection that is not controlled by a traffic signal and may include uncontrolled or stop-controlled intersections. Non-intersection locations are considered midblock for this analysis.

Environmental Factors include external risk factors in the built environment that should be mitigated, such as darkness that impedes driver vision at night.

These factors are further discussed in the next section.

Figure 2 uses a blue color scale to show the relative association of the identified risk factor within a station type compared to other risk factors. For example, arterial classification showed up strongly (dark blue shading) within all station types, but speed limits of at least 35 mph were much less prevalent (and therefore had a weaker association with severe crashes) in Urban station areas (light blue shading) than in auto-oriented station areas (dark blue shading).

Risk Factor	Station Typology				
	Urban	Urban Parking	Balanced Intermodal	Intermodal Auto-Reliant	Auto Dependent
Modifiable Roadway Design & Operational Factors					
Arterial Classification	88%	82%	68%	68%	62%
4+ Lanes	46%	57%	49%	52%	50%
35mph Speed Limit	15%	22%	52%	70%	74%
Proximity to transit	35%	10%	5%	2%	0%
Crash Location Type Factors					
Midblock Crossing	17%	14%	18%	28%	28%
Signalized Intersection	64%	41%	23%	28%	11%
Unsignalized Intersection	20%	44%	59%	44%	60%
Lighting Conditions					
Darkness	41%	46%	51%	43%	46%

Very Strong Association (>50)	Strong Association (25-49%)	Moderate Association (15-24%)	Low Association (<15%)

Figure 2 Key Risk Factors by Station Type
Source: BART Safety Action Plan for Roadways Task 3 Safety Analysis Findings

Toolbox Development

The toolbox of countermeasures was developed based on BART's HIN safety analysis, review of existing roadway safety best practices, and FHWA's Safe System Approach.

The Safe System Approach

The Safe System Approach (2024) is a traffic safety philosophy that accounts for the likelihood that people make mistakes, but the cost of those mistakes should not result in a loss of life or serious injury. In keeping with the FHWA's movement toward a Safe System Approach, the FHWA Safe System Roadway Design Hierarchy was used to inform the organization and evaluation of the countermeasure toolbox. The four tiers of the hierarchy are described below.

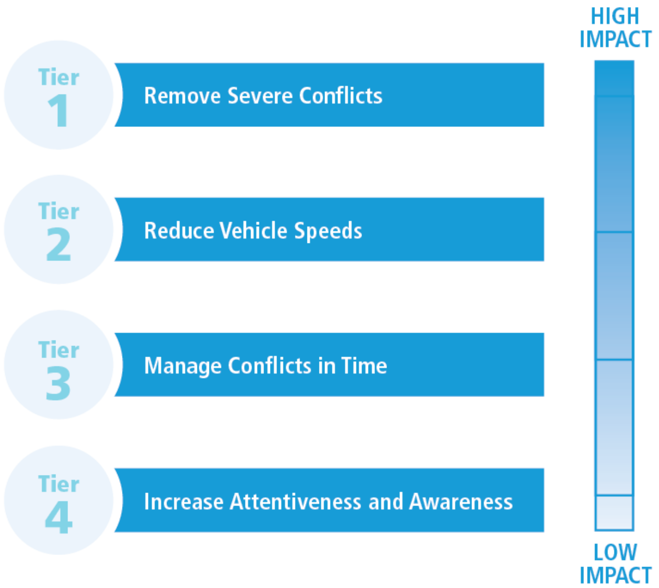

Figure 3 Adapted from FHWA Safe System Roadway Design Hierarchy
Source: FHWA 2024 and Ederer et al., 2023

Tier 1 - Remove Severe Conflicts: Countermeasures in this tier aim to eliminate high risk conditions by providing physical separation between users moving at different speeds or in different directions to minimize conflicts and reduce collision risk. This separation is typically accomplished with countermeasures that address intersection and roadway design.

Figure 4 Example of Tier 1 Interventions on Walnut Avenue in Fremont
Source: City of Fremont

Tier 2 - Reduce Vehicle Speeds: Countermeasures in this tier aim to implement appropriate speed limits and speed management strategies to limit crash severity and likelihood. Speed management countermeasures include elements of self-enforcing roadways (i.e., roadways that communicate the appropriate speed and user behavior through land use and design) and traffic calming to slow vehicles / enforce appropriate vehicle speeds.

Figure 5 Example of Tier 2 Interventions (Harrison Street, City of Oakland)
Source: City of Oakland

Tier 3 - Manage Conflicts in Time: Countermeasures in this tier aim to separate users in time with traffic signals or hybrid beacons to reduce crash likelihood.

Figure 6 Example of Tier 3 Interventions
Source: FHWA

Tier 4 - Increase Attentiveness and Awareness: Countermeasures in this tier aim to alert roadway users to potential conflicts and reinforce the concept of shared responsibility. Typical tier 4 countermeasures reinforce key elements of the roadway and remind users to stay aware and comply with the rules of the road.

Figure 7 Example of Tier 4 Interventions
Source: Google Maps Street View

1.1.1.1 Identifying Countermeasures

Multiple guides and toolboxes at the federal, state and local levels present countermeasures aligned with industry best-practice. The purpose of this toolbox is not to recreate this inventory, but to synthesize the existing body of research into a resource that supports BART's needs and goals for traffic safety within station areas.

This toolbox draws countermeasures from *NCHRP 926: Guidance to Improve Pedestrian & Bicyclist Safety at Intersections*, supplemented with general traffic signal and signage countermeasures included in the Caltrans Pedestrian Safety Countermeasure Toolbox, and FHWA's and Caltrans's Proven Safety Countermeasures lists. The team reviewed several industry standard sources to provide BART with comprehensive countermeasure recommendations. NCHRP 926 provides the most comprehensive guidance for this BART study, including estimated cost and public process evaluation scores for each countermeasure. The FHWA and Caltrans resources were also included to provide a broad range of countermeasures for BART's safety efforts. The countermeasures were evaluated based on a modified benefit-to-cost ratio, implementation feasibility, and equity considerations, as described below.

Note that lighting is included in the toolbox, but it is not evaluated in the same way as the other countermeasures. As the transportation industry increasingly recognizes the critical role of lighting for pedestrian and bicyclist safety at night, lighting needs to be treated as a fundamental part of a roadway system rather than as a countermeasure in isolation. In this new understanding, lighting should be considered an automatic element in any new or retrofit project where pedestrian or bicyclist travel is expected, even in small amounts.

1.1.1.2 Scoring System

Different metrics from the sources reviewed were used to evaluate and make context-specific recommendations for countermeasure effectiveness. To compare the relative benefit of countermeasures from different sources, the research team developed a scoring system with scaled components for level of effectiveness, financial cost, and implementation. Equity was considered in how countermeasures are implemented, assessed qualitatively in the context of three overarching topics: equity priority communities (EPCs), enforcement, and displacement. The extent to which different equity issues are relevant for each countermeasure is contextual. These are discussed in more detail within Equity Considerations. Finally, it is recommended that the implementation score be supplemented with evaluation through a local lens. Practitioners should draw on their local knowledge to determine whether a specific countermeasure is feasible. For example, some treatments may be prohibited due to local engineering code or city policy, even when they are known to be cost effective.

The level of effectiveness or ***Safe Trips to BART (STTB) benefit score*** was determined based on the FHWA Safe System Roadway Design Hierarchy. Each countermeasure was mapped to one of the four tiers and assigned a score according to Table 1. Tiers 1 and 2 (remove severe conflicts and reduce vehicle speeds, respectively) are considered by the research team to be equally critical for addressing a network's safety issues because speed is the primary mechanism for injury severity. Countermeasures in Tiers 1 and 2 are significantly more impactful on a network's safety than Tiers 3 and 4. A higher STTB benefit score indicates countermeasures with a greater safety benefit.

Table 1 Scoring Based on FHWA Tier

FHWA Tier	**STTB Benefit Score**
1	4
2	4
3	2
4	1

Cost scoring was determined based on the relative capital costs reported in the NCHRP 926 guidance. Countermeasures that require more time and resources to implement are assumed to have a higher cost and are given an STTB Cost Score from 1 to 4 as costs increase, as shown in Table 2 below. Given that the assessment of countermeasures will employ a benefit-to-cost (B/C) ratio in which the benefit is doubled and then divided by the cost, the STTB B/C ratio may range from 2:4 (Tier 4 countermeasure with high cost) to 8:1 (Tier 1 or 2 countermeasure with low cost). A lower STTB cost score indicates a lower cost range.

Table 2 Scoring Based on Cost

NCHRP 926 Estimated Cost	Cost **Max**	STTB Cost Score
$	$2,500	1
$$	$49,999	2
$$$	$150,000	3
$$$$	> $150,000	4

The ***implementation score*** was determined by inverting and normalizing the 5-point public process score developed as part of NCHRP 926. The public process score ranges from 1, which indicates that no public process is required to implement a countermeasure, to 5, which indicates that extensive public process would be required. As described in NCHRP 926, the five categories correspond to the following scenarios:

- 1 = No public process, engineering decision
- 2 = Public notice, engineering decision
- 3 = Minimal public process, engineering decision
- 4 = Moderate public process needed to build partner agency and community support
- 5 = Extensive public process needed to build community and political support

A high STTB implementation score indicates that a countermeasure requires limited or no public process. Note that this implementation score only considers the amount of public process required. Practitioners will also need to evaluate countermeasures through local lenses to determine how feasible the countermeasure is based on local policy and engineering code.

Table 3 Scoring Based on Implementation

NCHRP 926 Public Process	STTB Implementation Score	STTB Implementation Score (Normalized)
1	5	4
2	4	3.2
3	3	2.4
4	2	1.6
5	1	0.8

For supplementary signaling/signage countermeasures, source material from Caltrans and/or FHWA was used to assign these countermeasures to the NCHRP 926 ranges. Generally, simple signage and reprogramming of existing signals are a low relative cost investment ($ or $$) and introducing new signal heads/systems are a high relative cost investment ($$$$). The STTB score components were weighted and summed in the following manner for an aggregate countermeasure score:

(Benefit Score * 2 / Cost Score) + Normalized Implementation Score

This scoring system purposely deviates from a standard Benefit-Cost Analysis. This approach seeks to elevate countermeasures that are proven to have a greater ability to prevent fatal and severe injuries. Within the toolbox, the summary table of countermeasures by risk factor (Table 5) denotes countermeasures that are appropriate to address certain risk factors on their own and countermeasures that are either only appropriate under certain conditions or should not be installed as the sole treatment at a given location. This context further substantiates the need to weigh safety benefits higher than cost within the total score.

1.1.1.3 Equity Considerations

Equity issues are not as clear to assess as other metrics and seldom act in isolation; they are more likely a reflection of systemically underserving equity priority communities (EPCs) in urban and balanced station areas. Implementing countermeasures in EPCs should therefore be prioritized to address historical lack of investment but can also create unintended negative impacts regardless of intention. Some countermeasures do have specific equity considerations that should influence selection and/or implementation decisions, and these are detailed within the first summary table of the toolbox. Meaningful outreach and engagement are an essential part of introducing new countermeasures that address needs in communities with their respective safety challenges.

1.1.1.3.1 Equity Priority Communities

EPCs are defined by the Metropolitan Transportation Commission (MTC) as "…. Census tracts with a significant concentration of underserved populations, such as households with low incomes and people of color." (MTC, 2024) They have a relatively strong association with traffic risk in Urban and Balanced Intermodal station areas and a moderate association with traffic risk in Urban with Parking, Intermodal - Auto Reliant, and Auto Dependent station areas. Crash likelihood within EPC areas is much higher than non-EPC within Urban and Balanced station areas, but much lower than non-EPC within Urban Parking, Intermodal, and Auto station areas. This is consistent across all modes.

When working in EPCs it is important to recognize the validity of lived experience, especially when using professional judgement to recommend changes to a community. It is also advisable to use caution and humility to approach discussions where the community has not been consulted about their needs related to the project in question. EPCs are often over-surveyed without seeing their feedback realized on projects

Potential unintended adverse personal safety outcomes of countermeasures in these communities need to be recognized and weighed against traffic safety outcomes, such as those that create more enforcement opportunities.

1.1.1.3.2 Enforcement Implications

Speed and parking-related fines can pose a significant financial burden, thus exacerbating economic disparities in EPCs (Alvarado, 2021). Identifying countermeasures that do not require or encourage manual enforcement should be a priority in all communities.

Automated enforcement is one tool that can reduce the impact on historically marginalized communities, but only if it is not used to replicate enforcement practices that may have been affected by personal biases and criminal profiling. If considering automated speed or red-light cameras, their placement should not be based on citation locations but where crashes are recorded. Crash data has significant shortcomings, including documented underreporting in EPCs, but without more comprehensive and objective data such as measured speed or automated tracking of behaviors at intersections, there is a risk of increasing the policing of these communities. Fines should also be income-adjusted so they are meaningful for those who can afford it, and not excessively punitive for low-income groups.

Safety infrastructure interventions that do not require police enforcement should be prioritized before considering enforcement-type countermeasures suggested in this document.

1.1.1.3.3 Displacement

The positive relationship between rail transit, including transit-oriented development and improvements in access to rail transit, and property values is well documented. An affordability paradox exists where "low-income households which would benefit from additional accessibility… are forced to move by rising rents and housing costs" (Dong, 2017). (Alvarado, 2021). Safety countermeasures may be associated with unintended economic consequences imposed on station-adjacent neighborhoods.

Displacement is not directly caused by safety and accessibility projects; however, infrastructure and placemaking investments that increase access for a historically disinvested residential areas can make the area more attractive to a broader range of people. As a result, those who could previously afford to live in those communities are often priced out of housing and services or socially isolated if they remain.

Community-driven use of "placemaking" countermeasures is recommended, including pedestrian-scale lighting, bike infrastructure, sidewalk improvements, and changes in land use or pedestrian activity, informed by meaningful community engagement[1]. These interventions may be installed with the aim of improving safety but can also reinforce who has a "right to the city" and exclusion in public spaces through streetscape elements (Yeo, 2020). In proximity to encampments and people experiencing housing insecurity, consider resources such as those from the United States Interagency Council on Homelessness[2]. When working with cities and developers, there are other resources[3,4] available to inform financial and policy strategies for countering displacement pressures. BART has an opportunity to demonstrate leadership with their partners on this topic and to show that safe access to their stations can be achieved while preserving communities where safety is needed most.

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[1] https://cdn.ymaws.com/www.iap2.org/resource/resmgr/pillars/spectrum_8.5x11_print.pdf

[2] https://www.usich.gov/guidance-reports-data/federal-guidance-resources/19-strategies-communities-address-encampments

[3] https://www.arup.com/globalassets/downloads/insights/social-equity-toolkit-inclusive-growth-through-equitable-planning-us-cities.pdf

[4]https://www.austintexas.gov/sites/default/files/files/Housing_&_Planning/Equity%20Tool/Nothing%20About%20Us%20Without%20Us%20Racial%20Equity%20Anti-Displacement%20Tool_Final.pdf

2. Countermeasure Toolbox

The countermeasure toolbox consists of three summary tables, where each table presents the list of identified countermeasures by different categories.

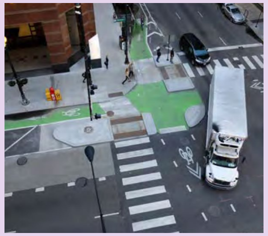
- Table 4 provides a description of each countermeasure along with an explanation of why it is effective, in what contexts it is most applicable, and a few considerations that may impact suitability. The table is organized by FHWA's Safe System Design Hierarchy Tiers to support countermeasure selection that is aligned with this guidance. Table contents are adapted from fact sheets for each countermeasure in NCHRP 926, supplemented with additional resources as needed, and sorted into FHWA Tiers by the research team.
- Table 5 presents a matrix of countermeasures against the specific risk factors identified in the Safe Trips to BART Task 3 HIN Safety Analysis. This table allows for countermeasures to be selected based on their ability to address key risk factors.
- Table 6 presents the list of countermeasures as they rank from highest to lowest score according to the equation outlined in the methodology. This table presents a benefit, cost, and implementation score that are combined to assess effectiveness and feasibility across the list of countermeasures.

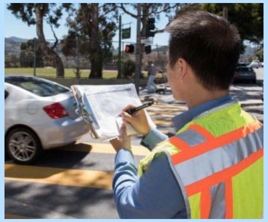
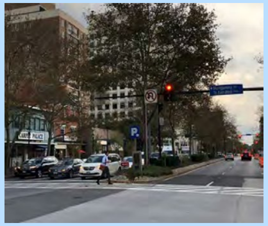
2.1 Countermeasures by FHWA Tier

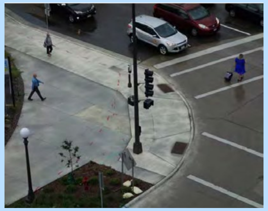
Table 4 Countermeasures by FHWA Tier, Adapted from NCHRP 926

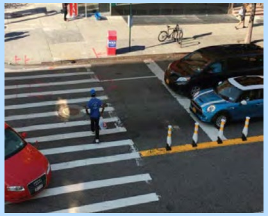
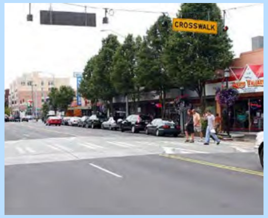
Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Tier 1: Remove Severe Conflicts				
Bikeways  *Source: NACTO*	Dedicated space allocated for bicycle travel with optional (but generally preferred) physical protection: including Class I, Class II, and Class IV	• Provides dedicated space for bicyclists and separates motorist and bicyclist flows. • Safety benefits increase with increased buffer zones and vertical separation.	• Corridors that are part of a planned bicycle network • Corridors that are being considered for a roadway reallocation project • Locations with high bicyclist volumes • Locations with documented bicyclist safety issues	**Safety Considerations** • Connectivity of facilities is critical for safety. • Vehicle speed and volume along a corridor should be considered when selecting a bike facility. Class II bike lanes should be protected by a buffer or physical barrier wherever possible. • When speeds are above 35 mph, a separated cycle track (Class IV) or shared use path (Class I) is recommended (FHWA, 2019). **Community and Equity Considerations** • New bike infrastructure can be perceived as a precursor to gentrification and displacement. While this may not be the case in every project, this belief stems from historical circumstances. • Any potential new bike infrastructure, especially in EPCs requires meaningful community engagement and building trusted relationships to identify where community needs align with bike infrastructure. • Bikeway projects may be a result of other market pressures in the area and anti-displacement policies should be considered holistically as part of a new project even if it is not associated with housing.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Crossing Barriers  *Source: NCHRP*	Continuous barrier that channelizes pedestrians away from a dangerous crossing	Designed to deter pedestrians from crossing at locations with an elevated risk of being struck by a vehicle	Locations with a history of risky pedestrian crossing behavior or crashes which cannot be resolved by other intersection design treatments	**Safety Considerations** • Barrier does not resolve crossing demand and can create more risky behavior. Last resort countermeasure that is <u>not recommended</u> in most cases. • Safe crossings should be provided nearby • Installation should include wayfinding to alternative crossing locations • Long term should be replaced with a safe crossing **Community and Equity Considerations** • Increases opportunities for enforcement, despite California's decriminalization of "jaywalking".
Crossing Islands  *Source: NCHRP*	Refuge areas at least 6-8 feet wide for pedestrians and bicyclists between vehicle travel lanes of opposing directions at intersections and midblock locations	Crossing islands reduce crossing distances and allow pedestrians and bicyclists to focus on crossing one direction of traffic at a time.	• Midblock or intersection crossing locations • All roads with two or more lanes of through traffic in each direction and speeds over 25 mph • Uncontrolled crossings where traffic gaps are insufficient • Where space allows	**Safety Considerations** • Especially important across corridors with medium-high vehicle speeds and volumes • Landscaping should not obstruct visibility between pedestrians and approaching motorists. • Must be fully accessible with ramps or cut throughs and detectable warnings. Must provide sufficient space for people using wheelchairs and mobility devices. Audible or actuated crossing buttons need to be accessible. • Midblock locations should include an active warning beacon. • Bullnose refuges can pose a tripping hazard. • In some designs, a median may act like a crossing island, but medians are distinct from crossing islands.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Grade-Separated Crossings  *Source: NCHRP*	Overpasses and underpasses that provide crossings where no at-grade crossing is possible or connect off-road paths and trails across facilities such as freeways, high-speed, high-volume arterials, and rail tracks	The complete separation of pedestrians and bicyclists from vehicular traffic reduces the risk of collision at this point, provided the facility is accessible and clearly visible.	• Where at-grade crossing treatments are not possible or potentially unsafe, such as crossings of free-flow, high-speed highway ramps or railroads • Locations with high vehicle volumes, high-speed highways, railroad tracks, or natural barriers	**Safety Considerations** • All grade-separated crossings must comply with ADA standards. • This treatment should be regarded as a spot treatment in cases where there is no other option. • These should not be used in place of an at-grade crossing. **Community and Equity Considerations** • If placed in a residential area, the scale of the structure and potential construction and operational impact on surrounding houses should be considered. This may include lighting, crime, shading, and refuse.
Protected Intersections  *Source: NCHRP*	Include a corner protection island, a forward queuing area, and recessed bicycle and pedestrian crossings	They are designed to slow turning motorist speeds to induce yielding and to improve the sight line between motorists and bicyclists, reducing conflicts between turning motorists and through moving bicyclists.	• Urban areas • Signalized intersections with sufficient space to accommodate the design • High volumes of bicyclists and motorists, or medium to high volumes of bicyclists, motorists, and pedestrians	**Safety Considerations** • Mountable truck aprons can reduce turning speeds for passenger vehicles while accommodating the off-tracking of larger vehicles where a larger corner radius is necessary. • Protected intersections may require more space along the intersection approach than standard intersections; intersection right-of-way and roadside dimensions are typically more important factors than total roadway width. **Community and Equity Considerations** • The introduction of a European intersection treatment can be seen as a prelude to gentrification and displacement, similar to bike lanes.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Tier 2: Reduce Vehicle Speeds				
Appropriate Speed Limits  *Source: NACTO*	Speed limits that reflect the likelihood of conflicts along a corridor	Reduction of fatal and severe collisions is achieved through setting speed limits that enable vehicles to identify a potential conflict and slow down or stop before reaching the conflict point.	All street types in all contexts	**Safety Considerations** • Where speed limits are set by the 85^{th} percentile speed, physical interventions must be installed to reduce speeds along a corridor. • In jurisdictions where setting speed limits is more flexible, identify critical corridors and institute new speed limits with clear messaging. • Prioritize slow speed zones in areas with vulnerable users are likely to be: e.g., schools, elder care, medical facilities. • The rest of the treatments in this tier will enable lower speed limits over time.
Continuous Raised Medians  *Source: NCHRP*	Raised median separating opposing directions of traffic at intersections and midblock locations	Continuous raised medians can be used as an access management strategy to eliminate motorist left turns or at intersections to reduce speeds of vehicles turning left.	• Midblock crossing locations • Locations where left-turning motorists pose safety concerns	**Safety Considerations** • Landscaping should not obstruct visibility between pedestrians and approaching motorists. • Continuous raised medians may take up space that could otherwise be used for wider sidewalks, bicycle lanes, or on-street parking. • Where pedestrians or bicyclists are expected, medians should be transitioned into crossing islands at intersections and in appropriate midblock locations. In these cases, the medians should be 6-8 feet wide and include ADA access to the degree possible. • Midblock locations should also consider an active warning beacon.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Coordinated Signal Timing  *Source: NACTO*	A signal timing strategy to help manage traffic movement through a corridor.	Coordinated signal timing can be used to encourage slower speeds by timing a set of signals to allow vehicles moving at a certain speed to pass through a corridor without stopping. This concept is sometimes called a "green wave."	Corridors with densely spaced intersections (1/4 mile or less) (NACTO, 2013)	**Safety Considerations** • Progression speeds should be set at or below the target speed, which should be in line with the appropriate speed limit for the context.
Curb Extensions  *Source: NCHRP*	Also known as bulb-outs, curb extensions decrease the width of the roadway with a physical extension of the curb line.	Curb extensions increase visibility, reduce crossing distances, and slow turning traffic.	• Locations with permanent on-street parking	**Safety Considerations** • Curb extensions should not extend into travel lanes, bicycle lanes, or shoulders (Blackburn, Zeeger, & Brookshire, 2017). • Lower-cost alternatives such as bollards, temporary curbs, planters, or striping can be used to emulate concrete curb extensions. • Turning needs of larger vehicles should be considered in the design. • Curb extensions may support active bike signal actuation buttons that don't require the bicyclist to dismount.
Curb Radius Reduction  *Source: NCHRP*	A curb radius reduction reclaims space that had been part of the travelled way to protect pedestrians and bicyclists.	Reducing curb radii can reduce turning speeds by forcing sharper turns.	• Urban areas • Areas with low truck, but, or other large vehicle volumes	**Safety Considerations** • Curb radius should be chosen to accommodate the most frequent large design vehicle as opposed to the occasional large vehicle size. • A mountable truck apron may be used to accommodate larger vehicles.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Hardened Centerline  *Source: NCHRP*	Strip of raised centerline that may be accompanied by bollards that reduces the turning radius for left turns	Hardened centerlines can be used as an access management strategy to eliminate motorist left turns or at intersections to reduce the speeds of vehicles turning left.	• Intersection or midblock crossing locations • Locations where left-turning motorists pose safety concerns	**Safety Considerations** • Hardened centerlines can use temporary curbing with flexible delineators. • The hardened centerline should extend past the crosswalk to most effectively slow left-turning vehicles, but vertical elements should not be within the crosswalk. • Midblock locations should also consider an active warning beacon.
Raised Crossings  *Source: NCHRP*	• A vertical traffic control measure • Designed with ramps on each vehicle approach to elevate the entire crosswalk (raised crossing) or intersection (raised intersections) to the level of the sidewalk	• Can reduce vehicle speeds, reduce the need for curb ramps, and improve pedestrian and bicyclist crossing safety by improving motorists yielding • Increases visibility between modes	• School zones • Locations where motorists are failing to yield at pedestrian crossings • Slip lanes • Roundabout crossings • Shared-use path crossings	**Safety Considerations** • Do not use crossings on steep curves or roadways with steep grades where visibility is limited. • Consider storm water drainage in the design of the raised crosswalk • Noise may increase, particularly if trucks regularly use the route • Markings and signs should promote nighttime visibility of raised devices for bicyclists and motorists • Consider directional detectable tiles in addition to required truncated domes to assist with low vision and blind users. • Can face objections from emergency services
Roadway Reallocation / Rechannelization  *Source: FHWA*	Reduction of the number and width of lanes, reducing travel speed; the space can then be used to implement additional pedestrian and bicyclist safety treatments such bike lanes and median crossing islands.	• The number of lanes on a roadway determines how far pedestrians must cross at an intersection and how many conflict points might exist. • Often completed to improve access management, increase bicycle and pedestrian access, and enhance roadway safety.	• Priority bicycle and pedestrian routes • Urban and rural areas • Multilane roads	**Feasibility may be influenced by:** • Traffic volumes and mix • Left-turn movements • Crash types and frequency • Geometric data such as roadway widths, sight distance, and the number of driveways

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Speed Safety Cameras (SSCs)  *Textt: School Zone / Speed photo enforced* *Source: NPR*	• Speed measurement devices to detect vehicles that are exceeding the speed limit • Also called photo radar or automated speed enforcement (ASE)	• Can decrease injurious crashes and increase road safety by encouraging slower speeds. • Compliance can be high 99% for spot cameras. (Victorian Government, 2024) • License plate readers can be used to track average speed to encourage compliance on a corridor rather than at a single point.	Signalized intersections experiencing high vehicle speeds, high speed collisions, multimodal collisions	**Safety Considerations** • Automated enforcement should only be used as a supplement to traditional engineering and education countermeasures, never as a replacement for these measures **Community and Equity Considerations** • Creating an enforcement program within a jurisdiction may necessitate the establishment of a new traffic unit or the hiring of personnel to oversee the program • In order to build public trust, SSC programs should be transparent about the use of revenue from citations. Revenue generated from SSCs in some jurisdictions has been put back into safety programs, rather than to finance unrelated expenses for the city or county (FHWA, 2023).
Tier 3: Manage Conflicts in Time				
All-Walk Phase  *Source: NACTO*	Exclusive pedestrian phase at signalized intersections that allows pedestrians to cross in any direction Also known as a Barnes Dance or Scramble phase.	All-walk phases are low-cost treatments that can increase pedestrian safety by separating pedestrians and vehicles in time.	• Densely populated urban areas, often in downtown areas • Signalized intersection with high instances of turning-vehicle--pedestrian conflicts • High pedestrian volumes and either low-to-moderate vehicle volumes or high turning-vehicle volumes	**Safety Considerations** • Sidewalk spaces must be sufficient to handle a queue of pedestrians waiting to cross • May improve the efficiency of intersections in areas of high pedestrian activity and low vehicle volumes • These signal phases need to be combined with standard crossing phases, or the wait times may become an impediment to pedestrian mobility. • Hatched or continental crossing striping in the center of the intersection is recommended to indicate a difference in pedestrian crossing conditions. **Community and Equity Considerations** • Nonvisual guidance should be provided for pedestrians with low or no vision

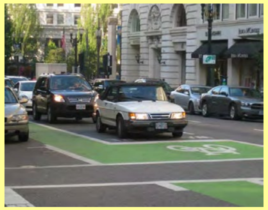
Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Bicycle Signals  *Source: NACTO*	• A traffic signal intended to control bicycle movements • Bicycle signals are needed to orchestrate a leading or protected phase for bicycle movements.	Initial findings show that bicycle signals may reduce vehicle-bicycle conflicts (Thompson, Monsere, Figliozzi, Koonce, & Obery, 2013).	• Signalized intersections with high bicycle volumes and high turning-vehicle volumes • Locations where a high-volume bicycle route crosses a major signalized intersection • Intersections with contraflow bike lanes or separated bike lanes • Intersections where a bicycle facility transitions from off-street to on-street • Complex intersections that may be difficult for users to navigate	**Safety Considerations** • Signals should be installed with actuation and appropriate detection for cyclists. • Separated or exclusive bicycle signal phases can increase delay for all users, which may decrease compliance. • FHWA requires an agency to request permission to apply for a leading bicycle phase. • It can be costly to implement as a red right arrow phase is needed, requiring a new signal head. • If this is not consistently applied throughout the city it can be confusing to all users how to act with these signals – vehicles expect to be able to right turn on red, and bikes may expect to be able to travel with through traffic when the bike lantern is red.
Extend Pedestrian Crossing Time  *Source: FHWA*	Increasing the length of the pedestrian walk phase based on a slower assumed speed of travel (3.0mph instead of 3.5mph)	This countermeasure allows more time for pedestrians to cross the street safely.	• Multilane facilities with long crossing distances • Signalized intersections with high pedestrian volumes or high volumes of pedestrians that require more time to move across the intersection	**Community and Equity Considerations** • Demographic and land use data may support decisions about where this countermeasure might be most needed, such as locations where vulnerable users are concentrated: e.g., elder care, schools, and medical facilities.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Leading Pedestrian Interval (LPI)  *Source: NCHRP*	• Provides pedestrians a head start when crossing at a signalized intersection • LPIs can be easily programmed into existing signals to give pedestrians the WALK signal a minimum of 3 to 7 seconds before motorists are allowed to proceed through the intersection.	• This extra time provides pedestrians with an opportunity to establish their presence in the crosswalk before motorists start turning. • Provides additional crossing time for those who need it • Increases the percentage of motorists who yield the right-of-way to pedestrians • Can minimize conflicts at intersections • Allows for more vehicles to clear the intersection before the next phase	• Signalized intersections • Medium to high turning-vehicle volumes and pedestrian volumes • Special cases: locations with particularly high elderly populations, high crash histories, or at school crosswalks • High incidence of failure to yield crashes or citations.	**Safety Considerations** • If an intersection has particularly high pedestrian traffic, consider lengthening the LPI or adding an exclusive pedestrian phase instead of an LPI, or installing a curb extension • LPI should be accompanied by an audible noise to inform visually impaired pedestrians that it is safe to cross • Consider combining with a no-right-turn-on-red restriction.
No Turn on Red Signs  *Source: NCHRP*	A sign posted at the signalized intersection for each approach where the turn restriction is desired	The purpose of this treatment is to eliminate conflicts between turning vehicles and pedestrians and/or bicyclists during a concurrent walk/bike phase.	• Signalized intersections • High volumes of right-turning vehicles and high volumes of bicyclists and/or pedestrians	**Safety Considerations** • Signs should be clearly visible to right-turning motorists stopped in the curb lane at the crosswalk • A common concern that comes up when restricting right turns on red is that this can lead to higher right-turn-on-green conflicts when there are concurrent signals. The use of an LPI can usually address this issue. • Can be combined with a red-light camera to enforce compliance **Community and Equity Considerations** • May increase opportunities for enforcement.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Passive Bicycle Signal Detection  *Source: NCHRP*	• The signal system automatically detects the presence of a cyclist to actuate a signal for the cyclist's phase • Loop detectors, video and microwave detection	Can deter unsafe cycling behaviors, such as disregarding red signal indications	• Signalized intersections that require users to be detected to actuate a signal for one or more movement • Intersections with bicycle signals and/or bicycle-specific phasing • Bike lanes approaching intersections with bicycle signals • Left-turn lanes with left-turn signals where bicyclists also turn left	**Safety Considerations** • Detection should be located in the most conspicuous and convenient location • Signal timing should be adjusted to account for the unique operating characteristics of bicycles • Redundancy in placement will assist with potential failures in the loop system. If the detection system stops working, bike users may need to take very risky maneuvers to turn on busy roads. • Signage and striping should be clearly provided to instruct bike riders on where to stand to trigger the signal.
Pedestrian Countdown Signals  *Source: NCHRP*	Indications designed to begin counting down at the beginning of the clearance interval, letting the pedestrian how much time is left in the crossing phase	Pedestrian signals and countdown signals provide positive guidance to pedestrians regarding the permitted signal interval to cross a street and prohibit pedestrian crossings when conflicting traffic may impact pedestrian safety.	• Any time a new pedestrian signal is installed • Crossings with exclusive pedestrian phases • Signalized intersections spanning wide streets • Crossings with medium-to-high volumes of pedestrians	**Safety Considerations** • MUTCD requirement for all newly installed traffic signals where pedestrian signals are installed **Community and Equity Considerations** • Provide supplemental nonvisual guidance for pedestrians with sensory restriction • Push-buttons should be within reach and operable from a flat surface for pedestrians in wheelchairs or with low or no vision.
Pedestrian Hybrid Beacons (PHBs)  *Source: NCHRP*	• Signals installed at unsignalized major street crossing locations to help pedestrians cross the street safely • Also called HAWKs	• Systemic safety improvement at uncontrolled locations with safety concerns or high frequency of pedestrian crashes • Reduces long pedestrian delay due to few available gaps in traffic • May be effective at reducing multiple threat crashes	• Urban or suburban multilane roadways • Higher speed roads (particularly at or above 35 mph) • Locations with high volumes of pedestrians and vehicles (AADT > 9,000); if higher volumes, 30 mph locations may be appropriate	**Safety Considerations** • PHBs may be appropriate where traffic signals are unwarranted. • Some cities use PHBs along heavily used bicycle routes to help bicyclists cross major streets. • Does not resolve the underlying safety issue

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Pedestrian Phase Recall  *Text: Don't push the button / Pedestrian crossing automated* *Source: Greater Greater Washington*	Places a continuous call for pedestrian service, without the need for pedestrian actuation, and results in pedestrian phases getting realized every cycle including that phase's walk and flashing don't walk (FDW) intervals	Reduces pedestrian delay at intersections compared to actuation, which in turn improves pedestrian safety as reducing pedestrian delay tends to improve pedestrian compliance (Pline, 2001).	• Any time a new pedestrian signal is installed • Signalized intersections spanning wide streets • Crossings with medium-to-high volumes of pedestrians	**Safety Considerations** Pedestrian recall may increase vehicular delay particularly at intersections with low to moderate pedestrian volumes (i.e., where there is no pedestrian actuation every cycle).
Protected Phases  *Source: NCHRP*	Providing an exclusive turn phase at a signalized intersection	Protected phases at intersections provide a way to separate vehicular traffic from pedestrian and/or bicyclist movements, particularly for left-turns when concurrent phasing would result in a conflict between modes.	• Urban areas, particularly in downtown locations • Intersections with high volumes of pedestrians or bicyclists and turning vehicles	**Safety Considerations** • Signal timing decisions should consider the needs of pedestrians, bicyclists, trucks, buses, and other motor vehicles • Signal timing decisions should consider the volume of turning motorists • Where protected turns are not consistently installed on a corridor or in a city it can result in confusion for users anticipating signal phases.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Reduce Cycle Lengths  *Source: NACTO*	• Reduction in the length of a signal cycle: the time from when one WALK or green bike interval ends until the next WALK or green bike interval ends, with all conflicting phases served in between • Cycle length may be fixed or variable.	Reducing the length of a signal cycle results in lower pedestrian and bicycle delay and has the potential to make roads safer for walking and cycling by reducing speeding opportunities (Furth, Halawani, Li, Hu, & Cesme, 2018).	• Urban areas, particularly in downtown locations • Intersections with high volumes of pedestrians or bicyclists and turning vehicles • Intersections with low to medium vehicle volumes	**Safety Considerations** Choice of signal cycle length generally involves a tradeoff of capacity, delay, and progression.
Tier 4: Increase Attentiveness and Awareness				
Active Warning Beacons  *Source: NCHRP*	• User-actuated flashing lights that supplement warning signs at unsignalized crossings • Lower-cost alternative to rapid flashing beacons or pedestrian hybrid beacons	Active warning beacons alert drivers that people are crossing the road and encourage motorist yielding.	• Unsignalized crossings • High pedestrian and/or bicycle volumes • Crossings where driver yielding is low	**Safety Considerations** • Appropriate when combined with other speed reduction countermeasures or locations with high pedestrian and/or bicycle volumes • Best suited for spot treatments; too many installations may reduce compliance • Does not resolve the underlying safety issue

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Advance Stop/Yield Lines  *Source: NCHRP*	Pavement markings placed 20 to 50 feet in advance of an uncontrolled and unsignalized pedestrian or bicycle crossing	Advance stop/yield signs improve the visibility of crossing pedestrians and bicyclists to motorists by increasing the distance between where motorists have stopped or yielded and the crossing.	Uncontrolled multilane crossings (at least two lanes in each direction)	**Safety Considerations** • Potential as systemic safety improvement at all uncontrolled crossings of roadways with at least four lanes and posted speeds of at least 30 mph • Compliance is low, and the requirement to stop is poorly understood
Bicycle Lane Extension Through Intersection  *Source: NCHRP*	Bicycle lane pavement markings that extend through intersections	These markings provide bicyclists with a clear, highly visible path through an intersection and alert motorists to the presence of bicycle through-traffic, encouraging turning motorists to yield.	• Locations with bicycle lanes or separated bike lanes where it is desired to delineate the bicycle crossing • Locations where right- or left-turning vehicles cross through moving bicyclists • Wide or complex intersections where the bicyclist path is unclear	**Safety Considerations** • Maintaining markings must be a high priority to prolong effectiveness; the long-term maintenance cost should be considered prior to installation. • These markings can encourage bikes to block the crosswalk.
Bike Boxes  *Source: NCHRP*	Marked boxes at intersections where bicyclists can wait at an intersection	Bike boxes can improve safety by increasing the visibility and predictability of bicyclists and encourage motorist yielding at the onset of a green signal.	• Signalized intersections with medium to high volumes of bicyclists and motor vehicles • Intersections where large vehicles are common • Intersections with high volumes of queuing bicyclists • Intersections with high volumes of turning vehicles and bicyclists going straight	**Safety Considerations** • Boxes may be disregarded by motorists if not commonly used by bicyclists (PBOT, 2010). • Should be accompanied by motorist right-on-red restrictions or dedicated turn pockets. • Distinction between waiting areas and turning boxes poorly understood by the community • These markings can encourage bikes to block the crosswalk

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Gateway Treatments  *Source: NCHRP*	Stop or Yield to Pedestrian signs (MUTCD R1-6 or R1-6a) placed on-street on each side of the travel lane ahead of an uncontrolled crosswalk	This treatment requires motorists to drive between the signs, resulting in a vehicle speed reduction between 4-10 mph (Van Houten & Hochmuth, 2017)	• Uncontrolled crossings on roads with speed limits of 30 mph or less • Uncontrolled crossings on roads with speed limits of 35 mph with average annual daily traffic levels below 12,000 (Van Houten & Hochmuth, 2017)	**Safety Considerations** • Signs should be placed on both sides of all travel lanes and may be located on a center line, median or crossing island, lane line, within a gutter, or near the curb, but they should not be placed within the crosswalk (Van Houten & Hochmuth, 2017) • The narrower the gap, the more effective the gateway treatment.
High-Visibility Crosswalk Markings  *Source: NCHRP*	Continental or ladder-style crosswalk markings placed at intersections or midblock crossings	High-visibility crosswalk markings improve pedestrian visibility to approaching motorists and can establish legal midblock crossings.	• All controlled intersections • Uncontrolled intersections that meet the requirements listed in MUTCD Section 3B.18	**Safety Considerations** • When vehicle speeds are over 30 mph, there is more than one lane in one direction, or AADT is above 9,000, there should be additional treatments present (Zegeer et al., 2017). • Midblock locations should also include warning signs and additional treatments that encourage motorist yielding
In-Street Pedestrian Crossing Signs  *Source: NCHRP*	• Stop or Yield to Pedestrian signs in the roadway at the centerline of an uncontrolled crosswalk • Spot treatment	• Associated with increased driver yielding and slight reductions in vehicle travel speeds when placed at marked crosswalks • Slight delay to vehicles • May increase safety and reduce delay for non-motorized modes	• Uncontrolled crossings of multilane roadways	**Safety Considerations** • The signs should be placed on a center line, on a lane line, or on a median island at the crosswalk. • Signs can be placed up to 50 feet away from a crossing. • The signs cannot be posted on another traffic control sign.

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Lighting*  *Source: FHWA*	Illumination at crosswalks and along the roadway *Note that lighting is considered a fundamental roadway design element that should be included in all roadway projects, and particularly those aiming to improve safety.	Can help increase visibility for pedestrians and bicyclists, particularly at approaches to crossings	• Signalized and unsignalized intersections, midblock • Special cases: at and near intersections in commercial or retail areas, near schools, parks, and recreation centers	**Safety Considerations** • Use uniform lighting levels • Pedestrian-scale lighting can increase the prominence of pedestrians on-street, and typically improves pedestrian amenity and feelings of safety • FHWA recommends luminaires be placed prior to the crosswalk in the direction of travel to provide adequate vertical illumination **Community Impacts** • Lighting may be disruptive to people experiencing homelessness/housing insecurity. Care should be taken to choose an appropriate lighting intensity and color to mitigate these impacts.
Mixing Zone Treatments  *Source: NCHRP*	Locations within intersections where bicyclists approach an intersection in a bicycle lane or separated bicycle lane that terminates in a shared motor vehicle turn lane	The provision of a constrained merging location encourages motorists to yield to bicyclists, reduce motor vehicle speed within the shared turn lane, and reduce the risk of hook crashes.	• Signalized intersections • Roadways with constrained right-of-way • Along bike routes or intersections with medium to high volumes of bicyclists • Roadways that can drop on-street parking near the intersection • Intersections with high volumes of turning vehicles and insufficient space for a bike lane • Along bike routes where there is a dedicated turn lane on the side of the street with the cycle track, but a bike signal is not appropriate	**Safety Considerations** • Mixing zone treatments should include yield entry markings, a motor vehicle entry area defined with flexible delineators or other physical devices, and a shared motor vehicle turn lane with shared lane markings. • May be most effective at intersections with 50 to 150 turning vehicles in the peak hour • May not be appropriate at intersections with very high peak automobile right-turn demand

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Parking Restrictions at Crossing Locations/ Daylighting  *Source: NCHRP*	• Removing parking space(s) on an intersection approach • No Parking sign (MUTCD R7 series)	Can improve the visibility between pedestrians and bicyclists with approaching motorists	• Approaches to intersections where parked vehicles block sightlines • Approaches to intersections with high volumes of pedestrians • Intersections with high frequencies of pedestrian-vehicle conflicts	**Safety Considerations** • In some cases, it may be necessary to provide physical roadway barriers to prevent motorists from parking near crosswalks, such as temporary curbing, planters, flexible delineators, or curb extensions. • These restrictions are not typically enforced and should be physically reinforced with curb extensions. **Community and Equity Considerations** • Communicate with nearby property owners and businesses who might be impacted by parking space removal • Increases opportunities for enforcement, consider means-tested fine structures.
Rectangular Rapid Flashing Beacons (RRFBs)  *Source: NCHRP*	• Placed on both sides of an uncontrolled crosswalk, below a pedestrian crossing sign, and above an arrow pointing at the crosswalk • RRFBs differ from standard flashing beacons by using a rapid flash frequency, brighter light intensity, and ability to aim the LED lighting • Can be passively or pedestrian actuated	• Feature an irregular, eye-catching flash pattern to call attention to the presence of pedestrians • Shown to significantly increase motorist yielding behavior at uncontrolled crosswalks, with motorist yield rates ranging from 34 percent to over 90 percent	• Roadways with low-to-medium vehicle volumes • Roadways with posted speeds less than 40 mph	**Safety Considerations** • RRFBs are good for two-lane streets, but less suited for multilane roadways • If multiple RRFBs are needed in close proximity, consider redesigning the roadway to address systemic safety challenges • Does not resolve the underlying safety issue

Countermeasure	Description	Why it works?	Applicable Contexts	Key Considerations
Two-Stage Bicycle Turn Queue Boxes  *Source: NCHRP*	• Designates an area outside of vehicle conflicts for bicyclists to wait for traffic to clear before proceeding in a different direction of travel • May be used for left or right turns	• Reduce conflicts between motorists and turning bicyclists • Useful at locations where bicyclists would have to merge across multiple lanes of traffic, would have to wait in a shared travel lane with motorists to turn, or at locations with separated bike lanes or side paths where it is not possible for bicyclists to merge into motor vehicle lanes in advance of the intersection	• Multilane intersections where bicyclists frequently turn left from a facility on the right side of the roadway • Cycle tracks or bike lanes with multiple adjacent motor vehicle travel lanes with high traffic speeds and/or traffic volumes • Special case: intersections where bicyclists must cross streetcar or light rail tracks to make a left turn	**Safety Considerations** • Consider a physical refuge (e.g., curb extension or jug-handle) for queuing bicyclists. • Consider a leading bike interval (LBI) • The queue box can also be used to help bicyclist make a right turn from a left-side bicycle lane or cycle track

2.2 Countermeasures by Risk Factor

Table 5 Countermeasures by Risk Factor

✓	Appropriate
✓[1]	Appropriate when combined with other speed reduction countermeasures
✓[2]	Most impactful with higher ped/bike volumes

Tier	Countermeasure	Arterial classification	4+ lanes	Posted speed ≥ 35 mph	Proximity to transit stops	Midblock locations	Signalized intersections	Unsignalized intersections	Darkness
		Modifiable Roadway Design and Operational Factors				*Location-Type Factors*			*Environmental Factors*
1	Protected Bicycle Lane	✓	✓	✓		✓			
1	Buffered Bicycle Lane	✓[1]	✓[1]	✓[1]		✓			
1	Striped (Conventional) Bicycle Lane	✓[1]	✓[1]	✓[1]		✓			
1	Crossing Barriers	✓	✓	✓		✓		✓	
1	Crossing Islands	✓	✓	✓	✓	✓	✓	✓	
1	Grade-Separated Crossings	✓	✓	✓		✓		✓	
1	Protected Intersections	✓[2]	✓[2]	✓[2]	✓[2]		✓		✓[1]
2	Appropriate Speed Limits	✓	✓	✓	✓	✓	✓	✓	✓
2	Continuous Raised Medians	✓	✓	✓		✓			

✓	Appropriate	**Arterial classification**	**4+ lanes**	**Posted speed ≥ 35 mph**	**Proximity to transit stops**	**Midblock locations**	**Signalized intersections**	**Unsignalized intersections**	**Darkness**
✓[1]	Appropriate when combined with other speed reduction countermeasures								
✓[2]	Most impactful with higher ped/bike volumes								
Tier	**Countermeasure**	***Modifiable Roadway Design and Operational Factors***				***Location-Type Factors***			***Environmental Factors***
2	Coordinated Signal Timing	✓	✓	✓			✓		
2	Curb Extensions	✓	✓		✓	✓[2]	✓	✓	
2	Curb Radius Reduction	✓	✓	✓[1]			✓	✓	
2	Hardened Centerline	✓	✓	✓[1]		✓	✓	✓	
2	Raised Crossings		✓[1]	✓[1]	✓[1]	✓[1]		✓[1]	✓[1]
2	Roadway Reallocation / Rechannelization	✓	✓	✓		✓	✓	✓	
2	Speed Safety Cameras	✓	✓	✓	✓	✓	✓	✓	✓
3	All-Walk Phase				✓[2]		✓[2]		
3	Bicycle Signals	✓	✓	✓			✓		
3	Extend Pedestrian Crossing Time	✓	✓	✓	✓		✓		

✓	Appropriate
✓[1]	Appropriate when combined with other speed reduction countermeasures
✓[2]	Most impactful with higher ped/bike volumes

Tier	Countermeasure	Arterial classification	4+ lanes	Posted speed ≥35 mph	Proximity to transit stops	Midblock locations	Signalized intersections	Unsignalized intersections	Darkness
		Modifiable Roadway Design and Operational Factors				*Location-Type Factors*			*Environmental Factors*
3	Leading Pedestrian Interval	✓	✓	✓	✓	✓[1]	✓		
3	No Turn on Red Signs	✓	✓	✓	✓		✓		
3	Passive Bicycle Signal Detection	✓	✓	✓			✓		
3	Pedestrian Countdown Signals	✓	✓	✓	✓	✓	✓		✓
3	Pedestrian Hybrid Beacons	✓	✓	✓	✓	✓		✓	✓
3	Pedestrian Phase Recall	✓	✓	✓	✓		✓		✓
3	Protected Phases	✓	✓	✓	✓		✓		✓
3	Reduce Signal Cycle Lengths	✓	✓	✓	✓		✓		✓
4	Active Warning Beacons		✓[1]	✓[1]		✓		✓	✓
4	Advance Stop/Yield Lines	✓[1]	✓[1]	✓[1]		✓		✓	

✓	Appropriate	Arterial classification	4+ lanes	Posted speed ≥35 mph	Proximity to transit stops	Midblock locations	Signalized intersections	Unsignalized intersections	Darkness
✓[1]	Appropriate when combined with other speed reduction countermeasures								
✓[2]	Most impactful with higher ped/bike volumes								
Tier	**Countermeasure**	***Modifiable Roadway Design and Operational Factors***			***Location-Type Factors***				***Environmental Factors***
4	Bicycle Lane Extension Through Intersection	✓[1]	✓[1]	✓[1]			✓	✓	
4	Bike Boxes	✓[1,2]	✓[2]	✓[1,2]			✓[1]		
4	Bike Boxes	✓[1,2]	✓[2]	✓[1,2]			✓[1]		
4	Gateway Treatments		✓		✓	✓		✓	
4	High-Visibility Crosswalk Markings	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]	✓[1]
4	In-Street Pedestrian Crossing Signs				✓[1]	✓		✓	
4	Lighting*	✓	✓	✓	✓	✓	✓	✓	✓
4	Mixing Zone Treatments	✓[1]	✓[1]				✓		
4	Parking Restrictions at Crossing Locations/Daylighting		✓		✓	✓	✓	✓	✓[1]

✓	Appropriate	**Arterial classification**	**4+ lanes**	**Posted speed ≥35 mph**	**Proximity to transit stops**	**Midblock locations**	**Signalized intersections**	**Unsignalized intersections**	**Darkness**
✓1	Appropriate when combined with other speed reduction countermeasures								
✓2	Most impactful with higher ped/bike volumes								
Tier	**Countermeasure**	***Modifiable Roadway Design and Operational Factors***				***Location-Type Factors***			***Environmental Factors***
4	Rectangular Rapid Flashing Beacons (RRFBs)	✓1	✓1	✓1	✓1	✓		✓	✓
4	Two-Stage Bicycle Turn Queue Boxes	✓2	✓2	✓2			✓		

*Note that lighting is considered a fundamental roadway design element that should be included in all roadway safety projects.

2.3 Countermeasures by Score

Table 6 Countermeasures by Score

Countermeasure	Benefit	Cost	Benefit: Cost Score	Implementation Score	Total Score
*Total Score = (Benefit Score * 2 / Cost Score) + Normalized Implementation Score*					
Curb Extensions	4	2	4:2	5	**10**
Curb Radius Reduction	4	2	4:2	5	**10**
Hardened Centerline	4	2	4:2	5	**10**
Appropriate Speed Limits	4	1	4:1	2	**8.6**
Speed Safety Cameras	4	1	4:1	2	**8.6**
Crossing Islands	4	2	4:2	3	**8.4**
Raised Crossings	4	2	4:2	3	**8.4**
Continuous Raised Medians	4	2	4:2	2	**7.6**
Extend Pedestrian Crossing Time	2	1	2:1	5	**7**
Leading Pedestrian Interval	2	1	2:1	5	**7**
No Turn on Red Signs	2	1	2:1	5	**7**
Pedestrian Phase Recall	2	1	2:1	5	**7**
Reduce Cycle Lengths	2	1	2:1	5	**7**
Crossing Barriers	4	2	4:2	1	**6.8**
Road Diets / Rechannelization	4	2	4:2	1	**6.8**
Bicycle Lanes	4	3	4:3	2	**6.6**
Protected Intersections	4	4	4:4	3	**6.4**
Bicycle Signals	2	2	2:2	5	**6**
Passive Bicycle Signal Detection	2	2	2:2	5	**6**
Pedestrian Countdown Signals	2	2	2:2	5	**6**
All-Walk Phase	2	1	2:1	3	**5.4**
Advance Stop/Yield Lines	1	1	1:1	5	**5**
Bicycle Lane Extension Through Intersection	1	1	1:1	5	**5**

Gateway Treatments	1	1	1:1	5	**5**
High-Visibility Crosswalk Markings	1	1	1:1	5	**5**
In-Street Pedestrian Crossing Signs	1	1	1:1	5	**5**
Two-Stage Bicycle Turn Queue Boxes	1	1	1:1	5	**5**
Grade-Separated Crossings	4	4	4:4	1	**4.8**
Protected Phases	2	1	2:1	2	**4.6**
Parking Restrictions at Crossing Locations/Daylighting	1	1	1:1	4	**4.2**
Active Warning Beacons	1	2	1:2	5	**4**
Bike Boxes	1	2	1:2	5	**4**
Rectangular Rapid Flashing Beacons (RRFBs)	1	2	1:2	5	**4**
Pedestrian Hybrid Beacons	2	3	2:3	2	**2.6**
Mixing Zone Treatments	1	2	1:2	3	**2.4**

*Note that lighting is not included in this table because it should be considered a fundamental roadway design element that is not graded against other countermeasures in terms of cost, benefit, and implementation.

3. Appendix: Summary of Traffic Safety Countermeasure Resources

The team reviewed seven industry standard countermeasure sources for this study: NCHRP 926, PedSafe, BikeSafe, FHWA Proven Safety Countermeasures, Caltrans Proven Safety Countermeasures, Caltrans Pedestrian Safety Countermeasure Toolbox, and NHTSA Countermeasures That Work. The resources available within each of these sources are described below.

NCHRP 926

The National Cooperative Highway Research Program (NCHRP) is a research program supported by AASHTO and administered by the Transportation Research Board (TRB). NCHRP 926 provides methodology intended to complement the online tools PedSafe and BikeSafe to provide a step-by-step process for countermeasure selection. The step-by-step process includes identifying and collecting data for the analysis, analyzing intersection safety, identifying treatment options, refining countermeasure options, and final countermeasure selection. A brief overview of each step is included below:

Identifying and collecting data for the analysis: The report identifies two strategies for countermeasure studies: reactive and proactive. Reactive studies are in response to areas with historical crashes, whereas proactive studies identify vulnerable areas at risk of future crashes. Reactive studies typically use crash-based (hotspot) data. Proactive studies typically use conflict (observational) data, exposure data, infrastructure data, and speed data in addition to crash data. Data for these studies are often imperfect, due to low numbers of crashes, underreporting, and gaps. Section 2.4 provides recommendations for working with imperfect datasets.

Analyzing intersection safety: The report identifies primary factors that contribute to both pedestrian and bicycle safety, including their (positive or negative) relationship with crashes (Tables 11 and 12). In addition to safety data, data and studies around comfort, observed behavior, and perceptions of safety and walkability – at a specific intersection or intersection approach – should be considered as well wherever possible. The most widely accepted data-driven tools/measures are Level of Traffic Stress (LTS), Bike Level of Safety (BLOS), and Pedestrian Level of Safety (PLOS).

Identifying treatment options: Countermeasure summary matrix (Table 25). The report organizes a pool of 35 countermeasures into three tiers, based on their effectiveness, and identifies which countermeasures are applicable for a given high-level safety performance issue.

- Tier 1: supports motorist yielding
- Tier 2: requires intervention to induce motorist yielding
- Tier 3: separates modes or requires motorists to stop

Their effectiveness in reducing crashes is evaluated using available data, including crash modification factors (CMFs), research, and best practice knowledge. The summary matrix also includes the required extent of public process on a scale of 1-5, an important consideration for implementation feasibility.

Refining countermeasure options: Specific countermeasures associated with each safety performance issue should be used as a starting point, but location-specific context must be considered in refinement, including traffic, land use, and roadway contexts. This context is used to identify priority users of the project area that the countermeasures will aim to serve. Table 28, the Conceptual Priority User Identification Matrix uses setting typology (rural, rural town, suburban, urban, and urban core), in tandem with typical characteristics (vehicle speed, bike demand, and pedestrian demand) to identify priority users.

Following the definition and documentation of project land use context, project roadway type, project and geometric constraints, policy and financial context, and priority users, the applicable countermeasure list should be refined by individually removing those no longer considered viable.

Final countermeasure selection: The final step assesses the viability of the refined list of countermeasures. Assessing viability considers operations, safety, and comfort prioritization; local and regional regulations, policies, and funding; and benefit-cost analysis. Table 29 in the report includes a summary of qualitative effects on operations, safety, and comfort of different countermeasures for different users/modes. The table also provides relative costs (capital and maintenance), spatial impact, and public processes typically required for countermeasure implementation. Upon consideration of these measures, priorities and tradeoffs between them must be assessed for final prioritization. Additional criteria may include crash history; benefit-to-cost ratio; modal plans; local, regional, and federal funding availability; and public interest and involvement. In addition to capital and maintenance costs, other costs and benefits may be quantified, including environmental, safety, congestion, reliability, access and equity, economic, health, and housing and transportation. NCHRP 220 offers tools and data for assessing these costs.

PedSafe and BikeSafe – FHWA

PedSafe and BikeSafe are online tools developed for the FHWA with complementary resources for countermeasure selection aimed at improving safety for pedestrian and bicycle modes, respectively. The tools help users identify a comprehensive list of potentially applicable countermeasures based on crash types or safety performance objectives. This comprehensive list is intended to be refined using their own complementary research and tools or that of other industry sources. The additional resources provided by PedSafe and BikeSafe are organized into four categories: background, statistics, analysis, and implementation.

The three basic steps of the online tool are:

- Enter the name of the location
- Select the goal of the treatment by performance objective(s) or crash type(s)
- Describe the site

Upon completing these three steps, the online tool generates a comprehensive list of potentially applicable countermeasures, each linked with further information and research to assist users in manually refining the list. Additional information includes a general description, purpose, considerations, estimated cost, and links to case studies.

The applicable countermeasures by performance objective and crash type are summarized in two matrices for each tool (pedestrians and bike).

FHWA/Caltrans Proven Safety Countermeasures

As California's governing Department of Transportation, Caltrans has many programs in place intended to address Vision Zero goals. Among these are Proven Safety Countermeasures (PSC), in line with FHWA Proven Safety Countermeasures. Both Caltrans and FHWA have the same list of 28 countermeasures, with a list of resources by countermeasure, to help inform selection and design considerations. In addition to the FHWA resources, Caltrans also includes California-specific guidance where available. The PSC includes data for each countermeasure that may be used in countermeasure selection, such as crash reduction potential. However, unlike previous sources, it does not present a refined/recommended methodology for countermeasure selection.

Each countermeasure has a PSC overview from the FHWA that typically includes a description, safety benefits, applications, and considerations. Safety benefits are generally quantified as approximate crash reduction potential percentages for all crashes and for injury crashes. Where data allows, these estimates may be further delineated by roadway type (arterials, freeways, roads, etc.). Some countermeasures also include benefit/cost ratios. Applications and considerations are described qualitatively. Applications identify cases where the selected countermeasure may apply and the corresponding types of analyses that would need to be performed to implement them. Considerations include further details to consider in the selection process, such as potential unintended knock-on effects, challenges with implementation, required studies, and participating agencies.

The breadth of resources provided by FHWA and Caltrans varies significantly by countermeasure, based on available research. For several countermeasures, the PSC overview is the only resource provided. For others, there is additional FHWA guidance, Caltrans guidance, TRB research, or other state DOT resources. The additional resources are broadly focused on design considerations and guidelines for implementation.

Caltrans Pedestrian Safety Countermeasure Toolbox

The Caltrans Pedestrian Safety Countermeasures Toolbox seeks to provide guidance for improving pedestrian safety across the State Highway System. The recommendations can be applied more broadly to address pedestrian safety concerns at different location types, but they should not be used in isolation. The guidance recommends referring to multiple sources and using engineering judgment when making decisions.

The toolbox contains 47 safety countermeasures that can be applied across a variety of roadway contexts. Countermeasures are grouped into five categories:

1. Signal Timing and Phasing
2. Intersection and Roadway Design
3. Signs and Markings
4. Pedestrian Crossings
5. Other

Each countermeasure is presented with a title, icon, description, example of treatment locations, and notes with additional information that may be useful. While many of the countermeasures presented are associated with a CMF value, some are not. The countermeasures that do not have a CMF are linked to research that supports how and why they are effective. The toolbox includes guidance about how to navigate the CMF database to find additional information about some of the presented countermeasures.

The toolbox also contains summary tables that associate countermeasures with collision conditions, location contexts, relative costs. Each category of countermeasures is discussed in the context of other guides and policies that apply in the State of California including the Caltrans Complete Intersections Guide, the CA MUTCD, and the CA Highway Design Manual. This outlines the procedures and design standards that may apply to different countermeasures presented as part of the toolbox. A full list of resources and references is provided in the appendix.

NHTSA Countermeasures That Work

The National Highway Traffic Safety Administration (NHTSA) is a government agency responsible for ensuring the safety of motor vehicles and road users in the United States. It develops and enforces safety standards, conducts vehicle crash tests, and supports state and local safety programs to reduce traffic fatalities and injuries. NHTSA's "Countermeasures That Work" helps State Highway Safety Offices (SHSOs) implement evidence-based countermeasures to improve road safety. This guide outlines effective strategies or countermeasures that can be used to reduce dangerous driving behaviors and enhance overall roadway safety.

"Countermeasures That Work" contains comprehensive summaries of countermeasures, categorized into topic areas such as impaired driving, distracted driving, speed management, and pedestrian safety. It evaluates the effectiveness, cost, and ease of implementation of each countermeasure and provides star ratings to guide decision-making. Countermeasures are developed through research, analysis of road safety issues, and evaluation of the real-world impact of different strategies. Each countermeasure's implementation timeline, costs, and evidence of effectiveness are provided, allowing SHSOs to tailor their traffic safety plans based on their unique needs and circumstances.

Additional Resources

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