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Framework for Selection and Evaluation of Bicycle and Pedestrian Safety Projects in Virginia

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16. Abstract

The Virginia Department of Transportation's (VDOT) Bicycle and Pedestrian Safety (BPS) Program provides funds for implementing short-term, low-cost bicycle and pedestrian safety projects in Virginia. This initiative is administered by evaluating each project application on a case-by-case basis. The current evaluation process does not include a direct linkage between the selection criteria and conditions at the site that might be hazardous to non-motorized travel. This significant limitation has resulted in the desire for a new methodology for project selection and evaluation.

This study developed a four-component framework for administering the BPS Program. In this framework, analysis procedures were identified for each component that can be used for identifying hazardous locations, determining causal factors, establishing performance measures, and determining potential countermeasures. The framework was then applied for selecting an appropriate safety treatment and for prioritizing a set of safety projects requested for funding.

To demonstrate the applicability of the framework, five case studies were conducted at locations in and around Charlottesville, Virginia. The prioritization process was demonstrated using the results of the case studies. The study findings showed that the framework synthesizes existing practice into a systematic approach for identifying bicycle and pedestrian hazardous locations and selecting appropriate countermeasures for implementation. The study also established the need for evaluation studies on safety treatments after implementation, as the effectiveness of many bicycle and pedestrian safety countermeasures are not well established.

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FINAL REPORT

FRAMEWORK FOR SELECTION AND EVALUATION OF BICYCLE AND PEDESTRIAN SAFETY PROJECTS IN VIRGINIA

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ABSTRACT

The Virginia Department of Transportation's (VDOT) Bicycle and Pedestrian Safety (BPS) Program provides funds for implementing short-term, low-cost bicycle and pedestrian safety projects in Virginia. This initiative is administered by evaluating each project application on a case-by-case basis. The current evaluation process does not include a direct linkage between the selection criteria and conditions at the site that might be hazardous to non-motorized travel. This significant limitation has resulted in the desire for a new methodology for project selection and evaluation.

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FINAL REPORT

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INTRODUCTION

Safety is an important issue with the non-motorized travel modes of walking and bicycling. According to the National Highway Transportation Safety Administration (NHTSA), there were 4,784 pedestrian fatalities, 773 bicyclist fatalities, 61,000 pedestrian injuries, and 44,000 bicyclist injuries in 2006,[1] accounting for nearly 13 percent of all crash-related injuries and fatalities. Considering the low levels of walking and bicycling (around 9 percent of total trips) relative to other modes of travel, these numbers indicate the magnitude of risk faced by pedestrians and bicyclists. Mobility and accessibility are still the primary factors used in bicycle and pedestrian planning; safety is a secondary consideration.

For many years in highway safety, emphasis was mainly on increasing the safety and mobility of motor vehicles and no significant attention was given to pedestrians and bicyclists. Land use patterns were also oriented toward motor vehicles. This trend continued until the early 1990s, when the Federal Highway Administration (FHWA) recognized walking and bicycling as important modes of transportation and placed emphasis on enhancing safety and mobility of pedestrians and bicyclists to encourage use of these modes.

Recently, the impetus toward pedestrian and bicyclist safety gained further momentum with the passage of the Safe, Affordable, Flexible, and Efficient Transportation Equity Act (SAFETEA-LU) in 2005.[2] In particular, SAFETEA-LU created a program called Safe Routes to School (SRTS) to make bicycling and walking to school safer and more appealing for children. SRTS provides funding for a wide variety of programs and projects, from building safer street crossings to establishing programs that encourage children and their parents to walk and bicycle safely to school.

The Virginia Department of Transportation (VDOT) addresses bicycle and pedestrian safety through a variety of programs that provide funding for studies and safety improvement projects. Further, VDOT has a policy to consider bicycle and pedestrian accommodations starting in the early phases of construction and maintenance project development. VDOT's Bicycle and Pedestrian Safety (BPS) Program is specifically created within VDOT's Highway Safety Improvement Program (HSIP) for implementing safety projects addressing bicycle and pedestrian crashes or their potential for occurring.[3] Projects target reduction in the number and severity of, or the risk of and exposure to, crashes at or near locations, sections, and elements on any public road, pathway, or trail. The intent of this program is to promote improvement projects that address a known safety problem, are small in scale, and can be completed quickly.

The BPS Program is currently administered by evaluating each project application on a case-by-case basis using four criteria: problem identification, proposed solution, project schedule, and cost. The current evaluation process does not include a direct linkage between the selection criteria and conditions at the site that might be hazardous to non-motorized travel. This significant limitation resulted in the desire for a new methodology for project selection and evaluation.

A systematic framework for administering the BPS Program should address the following issues:

- How can locations that are hazardous to pedestrians/bicyclists be identified?
- What are the engineering deficiencies that make these locations hazardous?
- Can we eliminate these deficiencies? If so, how?
- How do we know we have effectively removed the hazard?
- How do we prioritize candidate projects for funding?

Although many national and international studies have tried to answer one or more of these issues, none has developed a framework that comprehensively addresses them all.

PURPOSE AND SCOPE

The purpose of this study was to develop a framework, encompassing different methods and tools, for identifying hazardous locations and selecting countermeasures to eliminate the hazards. To complete the process, guidelines were developed for prioritizing safety treatments for funding and implementation.

The safety measures examined in this study were strictly within the "engineering" realm. Other measures, which pertain to enforcement and education, are an integral part of the BPS Program, but they were not explored in this study.

METHODS

The following tasks were conducted to achieve the study objectives:

1. *Literature review*: An extensive review of the bicycle and pedestrian safety literature associated with pedestrian/bicycle hazards, countermeasures, evaluation criteria, and prioritization methods was conducted. In addition to studies conducted by various state departments of transportation (DOTs), FHWA, universities, and research institutes, international efforts in bicycle and pedestrian safety were reviewed.

2. *Determination of the state of the practice.* A survey was prepared and sent electronically to selected VDOT staff responsible for the planning, design, construction, maintenance, and operation of bicycle and pedestrian facilities. This survey was also sent to 18 state DOTs, 12 Virginia city/county engineers, and 14 MPOs that have effectively addressed bicycle and pedestrian safety issues. Another survey was distributed to 14 bicycle and pedestrian advocacy groups in Virginia to obtain the perspective of the local community. The survey instruments, along with the results, are provided in Appendices A and B.

   Meetings and discussions were also held with traffic engineers, transportation planners, and bicycle and pedestrian activists in various counties of Virginia. Those interviewed included:

   - Allen Turnbull, Executive Director, BikeWalk Virginia
   - Angela Tucker, Development Services Manager/Neighborhood Development Services, City of Charlottesville
   - Charles Denney, Bicycle and Pedestrian Program Manager, Arlington Department of Transportation
   - David Patton, Statewide Bicycle and Pedestrian Coordinator, VDOT
   - John Lassiter, Transportation Planner, Culpeper District/VDOT
   - John Stevenson, Transportation Engineer, City of Norfolk
   - Mark Jamison, Traffic Engineer, Roanoke City
   - Pearl Windle, Program Manager, Virginia Department of Motor Vehicles
   - Stephen Read, HSIP Manager, VDOT
   - Travis Campbell, Transportation Planner, City of Virginia Beach
   - Yon Lambert, Pedestrian and Bicycle Program Coordinator, City of Alexandria.

3. *Identify bicycle and pedestrian safety hazards*. Based on the literature review and surveys, sites and conditions that are typically hazardous to bicycle and pedestrian travel were identified. Factors common to hazards and their respective mitigation strategies were determined.

4. *Establish performance measures (PMs).* By using the results of Tasks 1 and 2, measures for assessing the effectiveness of countermeasures were developed. These measures also serve as a linkage between hazards and safety mitigation strategies so that appropriate countermeasures can be identified for different hazards.

5. *Identify hazard mitigation strategies.* Potential strategies to correct the safety hazards identified in Task 3 were developed based on PMs identified in Task 4. Analytical tools such as the FHWA's PEDSAFE,[4] BIKESAFE,[5] and the Pedestrian and Bicycle Crash Analysis Tool (PBCAT),[6] which contain files of mitigation strategies, were examined for their ability to identify the corrective measures.

6. *Develop project selection and prioritization methodologies*. Using the PMs developed in Task 4, a process for identifying the most appropriate hazard mitigation strategies for specific bicycle and pedestrian high-risk situations was formulated. Another methodology for prioritizing safety projects was also developed, based on aggregate PMs.

7. *Conduct case studies.* For illustrative purposes, the methodology was applied to a representative group of potentially hazardous bicycle and pedestrian activity locations to determine whether hazards existed and, if so, to examine what alternative treatments could be considered and which should be selected for implementation.

RESULTS AND DISCUSSION

Literature Review

Several methods have been developed for identifying pedestrian and bicyclist hazardous locations. Deficiencies and causal factors are identified using crash analysis or through surrogate measures such as conflicts. PMs are established based on causal factors to evaluate the effectiveness of countermeasures. Crash analysis tools such as PBCAT and expert systems such as PEDSAFE and BIKESAFE provide countermeasures for many hazardous locations.

PEDSAFE is an online system designed to assist practitioners with the selection of countermeasures to address pedestrian safety and mobility problems. It is based on the FHWA report entitled *Pedestrian Facilities User Guide—Providing Safety and Mobility*.[7] PEDSAFE provides a selection tool that allows users to refine their selection of treatments on the basis of site characteristics, such as geometric features and operating conditions, and the type of safety problem or desired behavioral change. The purpose of the system is to provide the most applicable information for identifying safety and mobility needs and improving conditions for pedestrians within the public right of way. Similarly, BIKESAFE is an expert system that allows the user to select appropriate countermeasures or treatments to address specific problems.

Both PEDSAFE and BIKESAFE include a large number of case studies to illustrate treatments implemented in communities throughout the United States.

Site-specific applications and evaluations of the countermeasures are available in the literature. However, there are few documented applications of planning that compare alternative safety treatments for a specific location before any is implemented. In addition, certain countermeasures that have been evaluated to be effective at one location were found to be not so effective at other locations.

Various methods have been developed by state planning and transportation agencies for prioritizing bicycle and pedestrian projects. For example, the Victoria Transport Policy Institute's guide to best practices in bicycle and pedestrian planning lists four important factors for prioritizing bicycle and pedestrian projects: level of demand, degree of barrier, potential benefits, and cost and ease of improvement.[8] Based on these criteria, a matrix was formulated as shown in Table 1 that was used to evaluate project proposals.

A quantitative process using weights was also proposed in the study. Each criterion is given a score on a scale of 1 to 5. The scores are then multiplied with the criteria weights and aggregated to obtain the overall score for each proposal. The proposals are then ranked based on this overall score. Table 2 shows the rankings based on weights.

Table 1. Criteria for Bicycle and pedestrian Planning

Criteria	**Demand**	**Barrier Reduction**	**Social Benefit**	**Affordability (low cost)**
Location 1	High	High	Medium	High
Location 2	Medium	Low	High	Medium
Location 3	High	Medium	High	Low
Location 4	Low	High	Medium	Low

Source: *Pedestrian and Bicycle Planning: A Guide to Best Practice.* Victoria Transport Policy Institute, Victoria, B.C., Canada.

Table 2. Weights Based on Project Ranking

	Demand	**Barrier Reduction**	**Social Benefit**	**Affordability (low cost)**	**Total (Score x Weight)**	**Ranking**
Weights	**4**	**3**	**2**	**2**		
Location 1	4	5	3	4	45	**1**
Location 2	3	2	5	3	34	**3**
Location 3	5	3	4	1	39	**2**
Location 4	2	4	3	1	28	**4**

Source: *Pedestrian and Bicycle Planning: A Guide to Best Practice.* Victoria Transport Policy Institute, Victoria, B.C., Canada.

State of the Practice

Surveys

Fourteen responses to the 44 surveys (see Appendix A) sent to VDOT staff, selected state DOTs, and Virginia city/county engineers and MPOs were received.

Six responses to the survey (see Appendix B) sent to the 14 advocacy groups were received.

The following observations were made from the analysis of the survey responses.

Engineers/Planners

- Most of the projects are intended to address pedestrian safety only without consideration of bicycle safety. Mobility and accessibility are the main foci for bicyclists and pedestrians from the engineers' perspective.

- Funding is the major area of concern for implementing safety projects that addresses pedestrians and bicyclists.

- Most of the organizations adopt a combination of citizen input, crash analysis, and input from advocacy groups, public hearings and site inspections to identify hazardous locations.

- Data collected and examined by the engineers for safety analysis include vehicle crash-related data such as crash type, motor vehicles involved, location of the crash, roadway characteristics, time of day, nature of traffic control, and adjacent land use. Most respondents from cities and counties indicated that these data are not usually available for crashes involving pedestrians and bicyclists.

- High-speed urban arterials that lack crosswalks and sidewalks are the most typical hazardous locations for pedestrians, according to most of the local government respondents. Some respondents also identified high-volume intersections as hazardous.

- According to most of the respondents, any section of the street or arterial that lacks bicycle accommodations is hazardous for bicyclists. Some respondents also indicated that intersections and interchanges are hazardous for bicyclists.

- Tools based on geographic information systems (GIS) are being used to map bicycle and pedestrian crashes; analysis tools such as PBCAT, PEDSAFE, and BIKESAFE are not known to most of the respondents.

- Countermeasures are selected from those that have been implemented, documented, and proven to be effective in reducing crashes. Other criteria for selection of countermeasures are cost, ease of implementation, and ease of maintenance.

- Sidewalks and crosswalks are the most common pedestrian safety treatments employed by the respondents, followed by signage, pavement markings, traffic calming measures, and pedestrian signals.

- Provision of bike lanes is the most common bicycle safety treatment.

- Most of the respondents do not have a process to evaluate safety treatments after they are implemented. Those who do evaluate safety treatments do not have a defined methodology and are confined to observations from site inspections.

- The effectiveness of the safety treatments is determined primarily based on public feedback, according to most of the respondents.

- Methods employed by the respondents to select projects include citizen meetings, policies adopted by the local governments, ratings by panel of experts, and public workshops.

Advocacy Groups

- The main function of these advocacy groups is to provide training, workshops, information dissemination, and policy research on bicycle and pedestrian safety and mobility.

- Motor vehicle speeds, absence of sidewalks, and lack of compliance are the major factors that make walking hazardous. Road design and motorists' unwillingness to share the road make biking hazardous;

- Arterials, intersections, and locations that lack bicycle and pedestrian accommodations are the most common hazardous locations.

- Traffic calming, pedestrian refuge areas/islands, crosswalk signals, bike lanes, and raised mid-block medians are some of the treatments advocated to counter the hazards.

- Very few of the respondents monitor implemented projects to evaluate their effectiveness.

Meetings and Discussions

The following key observations were made during the meetings and discussions with traffic engineers, transportation planners and bicycle and pedestrian activists in various counties of Virginia:

- There is very little effort to identify hazardous locations systematically. Most hazardous locations are identified based on anecdotal information and as a reaction to a severe or fatal crash.

- The main purpose of bicycle and pedestrian master plans is to provide accommodations. Safety, although specified implicitly, is not a major objective of these plans.

- With regard to the use of analytical tools for safety studies, most counties/cities/MPOs cited the lack of documentation for bicycle and pedestrian crashes as the reason for not being able to use some of the tools. GIS-based tools are used at some areas to map pedestrian and bike crashes and to maintain an inventory of the corridors and their facilities.

- Most of the counties relate bicycle and pedestrian safety treatments to traffic calming programs. They are of the opinion that traffic calming treatments enhance the safety of pedestrians and bicyclists and, hence, are part of the bicycle and pedestrian safety program.

- Much of the effort with respect to bicycle and pedestrian safety is directed toward high-activity areas such as schools, malls, universities, and downtown areas.

- Evaluations of the effectiveness of these safety treatments are almost never undertaken after implementation. Instead, lack of complaints from citizens is used as an indicator of effectiveness.

Developed Methodology to Select and Prioritize Projects

Development of the Framework

Based on the literature review and determination of the state of the practice, a framework for administering bicycle and pedestrian safety programs was developed. As shown in Figure 1, the framework can be applied to select bicycle and pedestrian safety projects and to prioritize these projects for funding and implementation. The flowchart is divided into two parts: At the city/county level, the processes of identifying hazardous locations, evaluating countermeasures and incorporating the appropriate countermeasures into a safety project are carried out. At the state level, safety projects from different jurisdictions are compared and prioritized for funding and implementation.

The framework for identifying safety projects has four components:

1. identifying hazardous locations
2. determining causal factors
3. establishing measures of effectiveness
4. generating potential countermeasures.

Each component encompasses a set of methods adopted from the literature that is integrated to provide a comprehensive framework for evolving bicycle and pedestrian projects. These methods were selected based on their applicability for a wide range of pedestrian and bicyclist hazards, ease of use, and extent to which they are used in other states and countries. Case studies were conducted to demonstrate the applicability of the proposed framework.

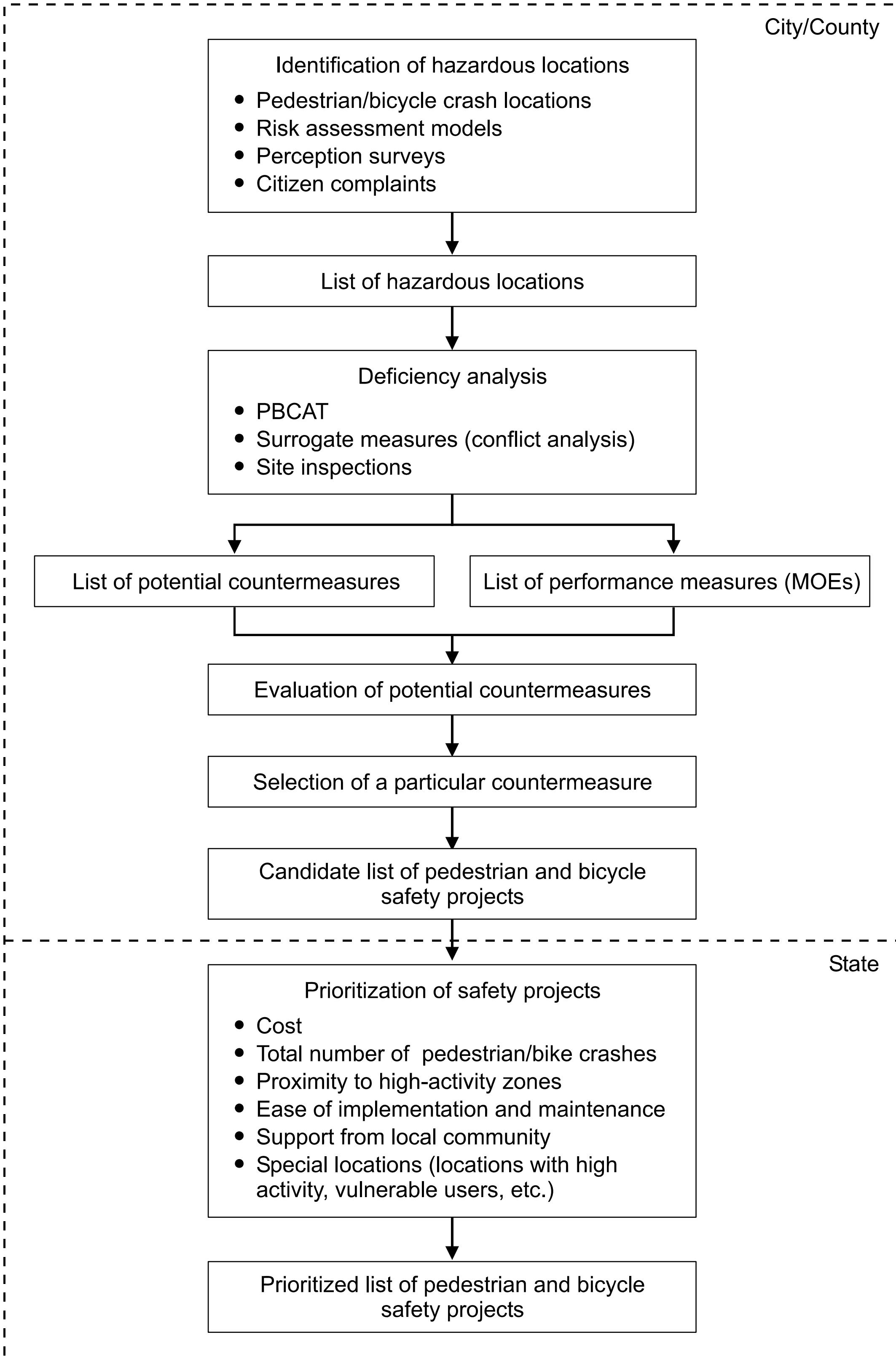

Figure 1. Framework for Selection and Prioritization of Bicycle/Pedestrian Safety Projects. MOEs = measures of effectiveness.

Identifying Hazardous Locations

Some of the most commonly adopted methods for identifying hazardous locations are identification of high pedestrian/bicycle crash locations, use of risk assessment models, use of intersection safety indices, use of perception surveys, and citizen input and advocacy. Through any or a combination of these methods, a set of locations that are hazardous for bicyclists and pedestrians may be identified.

Identification of High Pedestrian/Bicycle Crash Locations. Locations with an unusually high number of bicycle- and pedestrian-related crashes are obtained using the information from crash reports. These high crash locations (HCLs) are determined with the assistance of GIS-based tools[9] that identify zones (intersections or roadway stretches) that require safety enhancements. Crash rates are typically used to determine HCLs using the following process:

1. The location's crash rate is determined as the annual average number of crashes during the study period divided by the average daily traffic volume during the study period and is expressed as crashes per million vehicles.

2. The location is categorized into different groups based on features such as functional class of the road, area type, number of lanes, etc.

3. For each group, the critical crash rate is determined based on the average number of crashes within the group.

4. Those locations with crash rates that are higher than the critical crash rate of the group are classified as HCLs.

Data requirements include bicycle and pedestrian crash data indicating the nature and location of the crash; the driver, roadway, and environment; and the resulting crash severity.

Advantages of this method include the fact that an analysis of crashes also provided engineers with the probable factors that contribute to the crashes. The causal factors can then be used to develop countermeasures that can prevent such crashes from happening in the future.

The disadvantages of this method are that locations with a high number of reported crashes are selected and those with few or no crashes receive less attention. The extent of risk may not always relate to number of crashes. Moreover, since many bicycle- and pedestrian-related crashes with less severity are not reported, many hazardous locations may be missed in this analysis.

Use of Risk Assessment Models. These are statistical models that relate crash rates to contributing characteristics such as volumes, roadway geometry, traffic conditions, and land use. These models can be applied to a given set of locations to determine which locations pose a higher threat for pedestrian and bicyclist travel. Typical crash models are of the form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n$$

where

y	=	pedestrian/bicyclist crash rate
$x_1, x_2 \ldots x_n$	=	contributing characteristics (average annual daily traffic [AADT], pedestrian/bicyclist traffic, number of travel lanes, presence of crosswalks, presence of sidewalks/bike lanes, speed limit on the roadway, adjacent land use pattern, etc.)
$\beta_0, \beta_1 \ldots \beta_n$	=	coefficients obtained by fitting the model with existing data.

Advanced techniques for risk assessment models are described in NCHRP Synthesis 295.[10]

Data requirements include bicycle and pedestrian crash data indicating crash location; nature of the crash; the driver, roadway, and environment characteristics such as number of lanes, type of roadway, lane width, sidewalk and bike lane characteristics, and adjacent land use; and the resulting crash severity.

The advantage of using the risk assessment models is that they can be used to predict the extent of risk in places where crash data are not available based on the risk at other similar locations.

The disadvantages include the fact that risk assessment models suffer from the same drawbacks as those of the HCL method as they also depend entirely on crash records.

Use of Intersection Safety Indices. Macro-level bicycle and pedestrian intersection safety indices (Ped ISI and Bike ISI) have been developed[11] to use known intersection characteristics to prioritize crosswalks and intersection approaches proactively with respect to bicycle and pedestrian safety. Using variables that indicate a higher probability of risk for pedestrians or bicyclists, the Ped ISI and Bike ISI can be used to identify which crosswalks and intersection approaches have the highest potential for hazards within a particular jurisdiction. Once high-priority sites are identified, practitioners may conduct an in-depth evaluation at each site to determine which specific countermeasures would be appropriate to address any safety problems.

The data required include type of intersection control, intersection geometric characteristics such as number of lanes, traffic characteristics such as approach speed, traffic volumes, and the type of land use adjacent to the intersection.

Similar to risk assessment models, the advantages of using safety indices is that they can predict the extent of risk at intersections even if crash data are not available.

Disadvantages include that data were collected primarily during daytime and hence the model may not accurately predict the risk of night-time hazards.

Use of Perception Surveys. Perception surveys are designed to capture the perceived risk of road users rather than the actual or measured risk. A subset of pedestrians, bicyclists, and drivers are surveyed and asked to determine those locations that they perceive as hazardous. The locations are investigated further for potential safety treatments. An example of such a survey is available from the Pedestrian and Bicycle Information Center (PBIC).[12]

To use such a survey, the survey must be prepared, a subset of road users surveyed, and responses recorded for analysis.

The fact that crash data are not needed is one of the major strengths of this approach.

One of the main drawbacks of using this method is that locations with very little pedestrian or bicycle activity may not be identified as hazardous. In addition, the burden of administering the survey and processing the information makes conducting the survey on a regular basis difficult.

Citizen Input and Advocacy. The most commonly adopted method for identifying pedestrian and bicyclist hazardous locations is through citizen comments and concerns. Locations that evoke a significant number of complaints from road users and the local community are a good indication of potentially hazardous locations.

The data required are records of all citizen input about hazards to pedestrians and bicyclists.

The advantage of using this approach is that it is possible to identify the nature of the hazard. Often, the exact sequence of incidents that led to a crash or a near miss can be obtained from those who provide details, and this information can be used to determine the type of safety treatment required at the location.

The disadvantages are that citizen comments and concerns are often biased toward personal experiences. In addition, any publicity by media can lead to a large number of complaints, thereby distorting the actual picture.

Determining Causal Factors

Causal factors in design, installation, and maintenance of facilities and lack of adequate traffic control devices (signs, markings, signals) can be major contributors to making a location hazardous. In addition, the way a facility operates and the extent of its usage (by all modes) can also lead to hazards.

In identifying causal factors, special attention should be given to areas with high transit, pedestrian, and bike activity and the presence of vulnerable users such as young, elderly, disabled citizens and those with limited English proficiency. Special care should be given to ensure that the needs of these users are also incorporated into the identification process.

These causal factors can be broadly grouped into the following categories:

- *High motor vehicle speeds.* High vehicle speeds in relation to the speed limit creates a hazardous situation for pedestrians, bicyclists, and other motorists.

- *Poor sight distance and visibility of bicyclists and pedestrians.* Lack of sight distance might result in pedestrians and bicyclists making a wrong decision, resulting in a conflict or a crash, especially at crosswalks and intersections.

- *Restricted pedestrian/bicyclist mobility and accessibility.* In many cases, there may not be any facility for pedestrians/bicyclists, thereby restricting mobility and resulting in hazardous situations. The absence of a sidewalks, bike lanes, and crosswalks where pedestrian and bike activity warrants one is a typical example.

- *High motor vehicle volumes.* Roadways with high motor vehicle volumes create hazardous situations for pedestrians and bicyclists, primarily because of aggressive driving by motorists due to congested conditions.

- *Greater exposure levels of pedestrians and bicyclists.* At locations where pedestrians and bicyclists share the roadway with motor vehicles, they are exposed to potential conflicts. These shared areas can create potential hazardous situations.

- *Non-compliance of all road users with traffic laws.*

Causal factors can be identified using the following methods: crash analysis, site inspections, and analysis of surrogate measures.

Crash Analysis. Crash analysis provides information regarding the types of crashes that occur, where crashes occur, and the characteristics of crash victims (e.g., age, gender, injury severity). This information can be used to identify causal factors that make the site hazardous. PBCAT is a software product specially developed for analyzing bicycle and pedestrian crashes. PBCAT can be used to identify causal factors provided requisite crash data are available for all hazardous locations. These data include vehicle characteristics, pedestrian/bicycle information, driver information, roadway features, area characteristics, and environmental factors.

Site Inspections. Individual inspections of hazardous sites may also provide information on traffic volumes, impediments to pedestrian and bicyclist mobility, major vehicular movements, types of traffic control devices present, and adjacent land uses. Often, checklists are prepared to be used during site inspections so that all the information can be collected, organized, and compared across different sites.

Analysis of Surrogate Measures. In most cases, a location under investigation will not have associated crash records related to pedestrians and bicyclists. In such situations, surrogate measures based on conflicts can be used to identify hazards.[13] Some of the surrogate measures used include the frequency of pedestrian crossings at intersections and at mid-block locations; pedestrian/bicyclist and motor vehicle conflicts; percentage of pedestrians pressing the pedestrian call button; percentage of pedestrians crossing during the WALK, flashing DON'T WALK, and DON'T WALK indications; and driver yielding behavior.

Establishing Performance Measures

The next step in the framework is to establish PMs. PMs reflect the causal factors and help to determine the most appropriate strategy to address a particular hazard.

Based on the literature review, documented case studies, and the user manuals of PEDSAFE and BIKESAFE,[4,5] the most common causal factors along with related PMs are listed in Table 3. Depending on the specific location under analysis, a combination of PMs is used for countermeasure selection and evaluation.

Table 3. Causal Factors and Performance Measures

Causal Factors	Performance Measures
High motor vehicle speeds (in relation to speed limit)	• Reduction in average motor vehicle approach speed • Reduction in motor vehicle speed variance • Reduction in 85th percentile speed
Poor sight distance/visibility	• Changes in crossing behavior (number of aborted crossings, dart-out first half) • Reduction in night-time conflicts/crashes • Increase in night-time pedestrian/bicyclist activity
Restricted mobility/accessibility	• Reduction in average crossing time • Pedestrian/bicyclist level of service (LOS) • Reduction in average travel time to adjacent pedestrian/bicycle high-activity areas
High motor vehicle volumes	• Reduction in average daily traffic volumes • Reduction in peak hour factors • Motor vehicle LOS
High level of pedestrian/bicyclist exposure	• Increase in pedestrians/bicyclists using facility • Reduction in pedestrian/bicyclist conflicts • Changes in crossing behavior (number of pedestrians trapped in middle of road, abnormal running, aborted crossing) • Sufficient pedestrian signals and phase lengths (providing time separation to conflicts) • Distance to cross/provision of median refuge (reducing exposure)
Non-compliance with traffic laws	• Decrease in number of drivers not yielding/stopping at crosswalks • Decrease in number of pedestrians/bicyclists not following traffic signs, signals, and markings • Decrease in number of drivers stopping too close to or in crosswalk

Generating Potential Countermeasures

Based on the causal factors, a number of potential countermeasures can be identified to alleviate the hazard. To match countermeasures to hazards, expert systems such as PEDSAFE and BIKESAFE are good to start with. These systems generate a list of potential countermeasures based on the causal factors.

Tables 4 and 5 list the safety treatments advocated by PEDSAFE and BIKESAFE.

Table 4. PEDSAFE Countermeasure Types and Safety Treatments

Type of Countermeasure	Treatments
Pedestrian facility design	• Sidewalks and walkways • Curb ramps • Bollards, fences, and landscaping • Marked crosswalks and enhancements • Intersection and mid-block bulb-outs • Staggered mid-block crosswalks
Roadway design	• Bicycle lanes • Roadway/lane narrowing • Lane reduction • Driveway improvements • Raised medians • Two-way to one-way street conversions • Curb radius reduction • Improved right-turn slip-lane design
Intersection design	• Roundabouts • Modified T-intersections • Intersection median barriers
Traffic calming	• Curb extensions • Chokers • Crossing islands • Chicanes • Mini-circles • Speed humps • Speed table • Raised intersections • Raised intersections and pedestrian crossings • Gateways • Landscaping • Specific paving treatments • Serpentine design • Woonerfs
Traffic management	• Diverters • Full street closure • Partial street closure • Pedestrian streets/malls
Signals and signs	• Traffic signals • Pedestrian signals • Pedestrian signal timing • Traffic signal enhancements • Right-turn-on-red restrictions • Advanced stop lines • Signing
Other measures	• School zone improvements • Neighborhood identity • Speed-monitoring trailer • On-street parking enhancements • Pedestrian/driver education • Police enforcement

Source: Federal Highway Administration. *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System.* http://www.walkinginfo.org/pedsafe/. Accessed January 5, 2006.

Table 5. BIKESAFE: Countermeasure Types and Safety Treatments

Type of Countermeasure	Treatments
Shared roadway	• Roadway surface improvements • Reduce lane width • Bridge and overpass access • Tunnel and underpass access • Lighting improvements • Parking treatments • Median/crossing island • Driveway improvements • Access management • Reduce lane number
On-road bike facilities	• Bike lanes • Wide curb lanes • Paved shoulders • Combination lanes • Contra flow bike lanes
Intersection treatments	• Curb radii revisions • Roundabouts • Intersection markings • Sight distance improvements • Turning restrictions • Merge and weave area redesign
Maintenance	• Repetitive/short-term maintenance and cleaning • Major maintenance • Hazard identification program
Traffic calming	• Mini traffic circles • Chicanes • Speed tables/humps/cushions • Visual narrowing • Traffic diversion • Raised intersection
Trails/shared-use paths	• Separate shared-use path • Path intersection treatments • Intersection warning treatments • Share the path treatments
Markings, signs, signals	• Install signal/optimize timing • Bike-activated signal • Sign improvements • Pavement marking improvements • School zone improvements
Education and enforcement	• Law enforcement • Bicyclist education • Motorist education • Practitioner education
Support facilities and programs	• Bike parking • Transit access • Bicyclist personal facilities • Bike maps • Way finding • Events/activities • Aesthetics/landscaping

Source: Federal Highway Administration. *BIKESAFE: Bicycle Countermeasure Selection System,* http://www.bicyclinginfo.org/bikesafe/. Accessed January 5, 2006.

It should be noted that the treatments included in these applications are based on those that have been implemented for an extended period of time and/or have been proven effective through post-implementation evaluation studies. However, many other countermeasures are currently being implemented and evaluated. Hence, the list given here is not exhaustive, but it provides a reasonable list of alternatives to review before selecting a safety treatment.

Most often, a single countermeasure does not adequately address a hazard. In such cases, more than one countermeasure may be selected and implemented.

Application of the Framework

After going through the four-step process, cities/counties may select the most suitable countermeasure(s) for the hazardous location under investigation. This would result in a pedestrian/bicycle safety project. Each city/county would then submit proposals for such pedestrian/bicycle safety projects to the state. The state would prioritize the projects for funding and implementation. Methodologies for project selection by cities/counties and prioritization by the state are described in the following sections.

Project Selection Guidelines

The list of countermeasures generated in the framework can be evaluated against the PMs that are established based on causal factors. Using aggregate average or weighted criteria, an overall measure can be calculated for each alterative proposed safety treatment. This value can be used to select the most suitable set of safety treatments. A relative scoring scheme can also be used. The Victoria Transport Policy Institute's guide to best practices in bicycle and pedestrian planning enlists the different methods for qualitative and quantitative scoring schemes for selecting and evaluating projects.[8]

For the case studies, the following project selection guidelines were applied to select the most suitable alternative:

- From the candidate set of countermeasures, remove all the countermeasures that do not apply to the current location. For example, enhancements to transit stops when there are no transit stops at the location can be removed. Also remove those countermeasures that have already been installed at the selected location.

- Evaluate construction time period and implementation feasibility (right-of-way requirements, environmental clearance, etc) for each countermeasure and eliminate the countermeasures that are not feasible.

- Remove those countermeasures that cost more than the mandatory cap set by the state DOT. In the case of VDOT, this limit is $500,000 per project. However, if the city/county has funds to cover the balance, these countermeasures can be considered.

- Consider grouping or combining countermeasures if the benefit is enhanced. Strong engineering judgment and knowledge of the locality and neighboring community are required for this step.

Prioritization of Projects

To determine a county or statewide prioritization strategy for implementation of bicycle and pedestrian safety projects, a set of PMs different from those used to select countermeasures are adopted. These PMs reflect many factors other than safety, such as the economy, feasibility of implementation, and support from the local community.

Based on the literature, the following are typical PMs given for the project prioritization process:

- project cost
- ease of implementation and maintenance
- total number of pedestrian/bike crashes
- proximity to high-activity zones
- latent demand for pedestrian/bike activity
- support from local community
- level of pedestrian/bike activity
- opportunity to construct concurrently with an adjacent roadway projects
- connectivity
- demand for usage
- potential to attract new pedestrians/bicyclists
- presence of existing alternatives
- type of road network
- proximity to disadvantaged neighborhoods
- adjacent population density planned/projected land use, etc.

Projects can be evaluated against all or a subset of these PMs. The evaluation can be accomplished qualitatively or quantitatively using a rating system as discussed earlier.

Case Studies

To demonstrate applications of the framework, locations in and around the City of Charlottesville were selected for the case studies. Discussions with the local transportation officials led to the identification of five locations identified as hazardous as they existed. Even though detailed crash data were not available for these locations, there were a number of reported near misses, complaints of difficulty in walking/biking, and articles in the local newspaper documenting the hazardous nature of these locations.

At each location, the hazards, causal factors, PMs, and potential countermeasures were investigated using the framework developed in this study. Each location was inspected, and bicycle and pedestrian movements were observed for 2-hr periods in the morning and afternoon to determine the nature of hazards and causal factors. PMs were then selected using the list in Table 3 to reflect the deficiencies associated with the location under investigation. For demonstration purposes, countermeasures were then identified using PEDSAFE and BIKESAFE. In practice, it is recommended that an agency accumulate its own catalog of countermeasures to address. The project selection methodology is then used to select the most suitable set of countermeasures for each hazardous location.

Case Study 1: Intersection of Emmet Street and Morton Drive

Emmet Street (U.S. Route 29) is a major arterial in Charlottesville, serving the north-south traffic movements and the major commercial developments on Route 29. The intersection of Emmet Street and Morton Drive is just south of the intersection of U.S. Route 29 and the U.S. 250 Bypass (Figure 2). The land use around this intersection is mostly commercial, with a couple of fast food restaurants, a hotel on Morton Drive, and a restaurant and a local grocery store located on Emmet Street across from Morton Drive.

The Rivanna Trail, a hiking trail that encircles the City of Charlottesville, crosses Emmet Street at this location. Trail users have been requesting a crosswalk at this intersection since there is no convenient facility to get to the other side of the trail. The nearest crosswalk is about one-half mile south at the intersection of Emmet Street and Barracks Road, and there are no crosswalks north of the location.

Causal Factors

To determine the deficiencies in the system, bicycle and pedestrian movements were observed for a 2-hr period in the morning and afternoon. Site inspections were also conducted. Some of the key findings were as follows:

- Sidewalks were either missing or discontinuous along portions of Emmet Street at the intersection. As the U.S. Route 250 Bypass interchange is nearby, the entry and exit ramps made the sidewalks discontinuous. Foot tracks could be observed on the right side of Emmet Street South beyond the U.S. 250 bypass interchange.

- Crosswalks were marked only recently on two legs of the intersection. Crash barriers are present at the median of Emmet Street, north of the intersection, thereby blocking pedestrian movement. Crosswalks are not marked on the north approach of the intersection.

- The high speed and volume of vehicles on Emmet Street and the absence of any central refuge created a barrier for pedestrian movement, especially for users of the Rivanna Trail.

- There were no bicyclists during the hours of observation or during the site visits. Hence, bicyclist hazards and causal factors could not be established.

Figure 2. Intersection of Emmet Street and Morton Drive (looking south)

Based on these observations, some of the main causal factors at this location were as follows:

- restricted pedestrian/bicyclist mobility and accessibility
- greater exposure levels of pedestrians and bicyclists
- high motor vehicle speeds
- high motor vehicle volumes.

Performance Measures

PMs that would assess the extent to which the safety treatment would remove the deficiencies were established. Potential PMs included:

- pedestrian/bicyclist level of service (LOS)
- reduction in average travel time to adjacent pedestrian/bicycle high-activity zones
- reduction in average pedestrian crossing time
- reduction in motor vehicle approach speeds
- reduction in average daily traffic volumes.

Since this facility is a primary arterial, reductions in volumes and speeds may not be achievable. Because of the absence of any bike activity during the observation period, hazards to bicyclists could not directly be determined and hence the application was oriented toward removing pedestrian hazards. At present, this location provides significant intimidation to bicycle travel from other areas because of the necessity of traversing below an overpass on narrow shoulders and then entering the roadway with the traffic in a 40 mph stretch of arterials. There are no bicycle accommodations in the vicinity of the site. Any attempt here to provide for safe bicycle travel would need to be a part of a system-wide study for bicycle travel and beyond the scope of a localized safety project.

Countermeasures

A set of potential countermeasures was obtained by using PEDSAFE. The major criterion used was to enhance pedestrian mobility and accessibility. After providing the intersection characteristics such as area type, functional class, traffic volume, speed, number of lanes, and traffic signal features, the countermeasures noted in Table 6 were obtained. Treatments that were selected using the project selection methodology are italicized.

Selection of Safety Treatment

The remaining countermeasures, namely providing sidewalks and walkways with marked crosswalks, can be combined into a single project. This is because most literature[14] suggests that marked crosswalks are more effective when combined with other treatments.

Hence, the recommended safety treatment at this intersection is to provide marked crosswalks along with walkways and sidewalks.

Table 6. Countermeasures and Treatments Obtained Using PEDSAFE, Case Study 1

Type of Countermeasure	Treatments	Remarks
Pedestrian facility design	*Sidewalks and walkways*	
	Curb ramps	Already existing on all approaches
	Marked crosswalks and enhancements	
	Transit stop treatments	No transit stop nearby intersection
	Pedestrian overpass/underpass	May be an expensive option
Roadway design	Raised medians	Already existing on major approach
Traffic calming	Crossing islands	Insufficient right of way
Signals and signs	Traffic signals	Adequate on all approaches
	Pedestrian signals	Existing in two approaches
	Traffic signal enhancements	Adequate

Note: Treatments that were selected using PEDSAFE are italicized.

Case Study 2: Intersection of Alderman Road and McCormick Road

The intersection of Alderman Road and McCormick Road (Figure 3) is one of the busiest intersections in terms of pedestrian traffic within the University of Virginia area. The Observatory Hill dining hall is located on the south-west corner of the intersection. Most of the academic areas are located on McCormick Road. Hence, students walk along McCormick and cross Alderman at this intersection to reach the dining hall.

Striped crosswalks have been provided on all legs of the intersection with push button pedestrian signal heads and curb ramps.

During the last few years, recurring problems to pedestrian movements have resulted in several treatments being installed at this intersection, including changes to the signal timing plan; a "NO TURN ON RED" sign for right turns; and recently, the implementation of an all-red phase for pedestrians.

Causal Factors

To determine deficiencies, bicycle and pedestrian movements were observed for a 2-hr period in the morning and afternoon. A site inspection was also conducted. Some of the key findings were as follows:

- Pedestrian compliance with the "WALK" signal was very poor. Pedestrians use the striped crosswalk, but they cross whenever there is a gap in traffic;
- An all-red phase with a pedestrian "WALK" signal on all legs of the intersection has been implemented. This is beneficial during lunch hours when many students use the crosswalk to get to the dining halls. But at other times, the excessive waiting time between the push-button call and the appearance of the "WALK" signal results in very few pedestrians crossing during the all-red phase;
- Sight distance is limited for pedestrians on the south leg of Alderman Road because of vegetation in the southeast quadrant of the intersection;

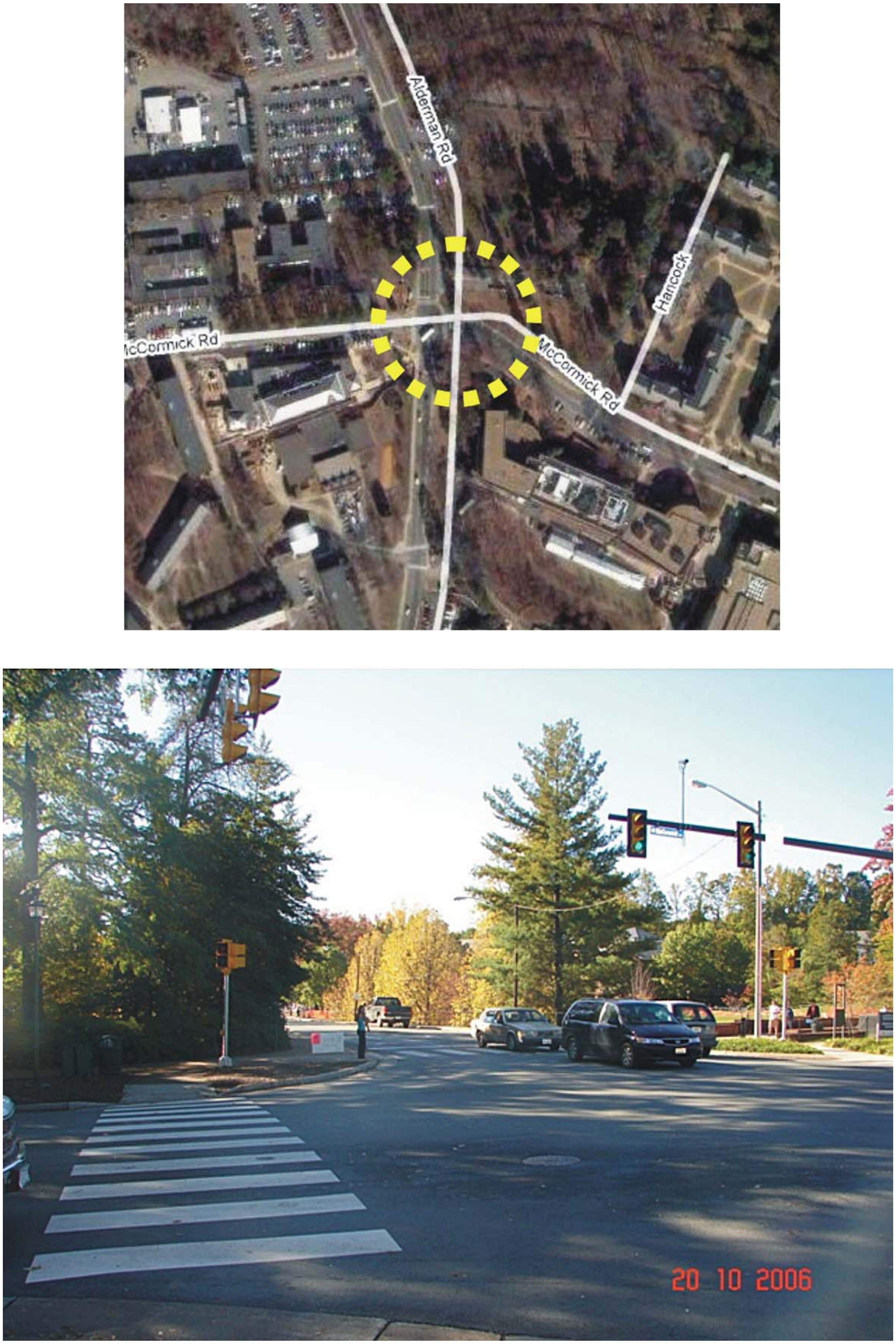

Figure 3. Intersection of Alderman and McCormick Road (looking north)

- Observations indicate that the lack of visibility of the ”WALK”/”DON’T WALK” signals and the lack of a clearance interval display on the pedestrian signal have probably resulted in very little usage of the push-button pedestrian signals.

- Although some lighting is provided, there is some question as to whether it is adequate for this intersection during night-time.

Based on these observations, the main causal factors at this location were:

- poor sight distance and visibility of bicyclists and pedestrians
- non-compliance of pedestrians with traffic laws.

Performance Measures

Based on the causal factors identified, potential PMs included:

- changes in crossing behavior (number of aborted crossings, dart-out first half)
- reduction in night-time conflicts/crashes
- increase in night-time pedestrian/bicyclist activity
- decrease in number of drivers not yielding/stopping at crosswalks
- decrease in number of pedestrians/bicyclists not following traffic signs, signals, and markings.

Since minimal bike activity was observed, hazards to bicyclists could not be determined and the study was more focused toward pedestrian hazards and countermeasures.

Countermeasures

A set of potential countermeasures for this situation was obtained and is shown in Table 7. Treatments that were selected using PEDSAFE are italicized.

Table 7. Countermeasures and Treatments Obtained Using PEDSAFE, Case Study 2

Type of Countermeasure	Treatments	Remarks
Pedestrian Facility Design	Marked crosswalks and enhancements	Crosswalks existing in all approaches
	Roadway lighting improvements	
Traffic Calming	Curb extensions	Will intrude into the motor vehicle lanes (can only be provided when a parking lane exists)
	Raised intersections	
	Raised pedestrian crossings	
	Specific paving treatments	
Signals and Signs	Recessed stop lines	Stop lines were not too close to the crosswalks
	Pedestrian signal timing	Retiming signals to eliminate the all-red phase
Other Measures	*Pedestrian/driver education*	
	Police enforcement	

Note: Treatments that were selected using PEDSAFE are italicized.

Selection of Safety Treatment

As seen from Table 7, traffic calming measures such as a raised intersection or specific paving treatments and lighting improvements are recommended for this location. The signal timing plans need to be changed to provide more opportunities for pedestrians to cross the intersection. Even though they are not part of the engineering domain, educating road users and increasing the level of enforcement are also recommended.

Case Study 3: Intersection of Whitewood Road and Hydraulic Road

This intersection is located close to Albemarle County High School (Figure 4). Hydraulic Road, a major arterial, has high traffic volumes and speeds relative to the 35 mph speed limit. With high pedestrian activity, it is essential that this intersection be maintained at high levels of safety for the schoolchildren.

Causal Factors

- There is very little accommodation for pedestrians at this intersection. On the west side of Hydraulic Road in front of the school, sidewalks have been widened to accommodate pedestrian activity; there are no sidewalks north of the school entrance.

- Only two of the four quadrants of the intersection have marked crosswalks, although pedestrian movements were observed in all quadrants. Pedestrian signals and push-buttons are provided at these crosswalks.

- A vertical curve sloping south to north encourages vehicles to move at higher speeds than the 35 mph speed limit.

- Sight distance is limited because of the geometry of the intersection, particularly for westbound vehicles.

- There is no median or central refuge provided for pedestrians to cross Hydraulic Road even though the roadway has six lanes at this location.

- There is no protected pedestrian phase at this intersection. A considerable amount of left-turning traffic was observed, and it overlapped with the pedestrian green times.

Based on these observations, the causal factors at this intersection were:

- high motor vehicle speeds
- poor sight distance and visibility of bicyclists and pedestrians
- restricted pedestrian/bicyclist mobility and accessibility
- high motor vehicle volumes
- greater exposure levels of pedestrians and bicyclists.

Figure 4. Intersection of Whitewood Road and Hydraulic Road (looking west)

Performance Measures

PMs associated with these causal factors are as follows:

- reduction in motor vehicle speed variance
- reduction in 85th percentile speed
- changes in crossing behavior (number of aborted crossings, dart-out first half)
- reduction in average crossing time
- pedestrian/bicyclist LOS
- reduction in average daily traffic volumes
- increase in pedestrians/bicyclists using the facility
- reduction in pedestrian/bicyclist conflicts
- changes in crossing behavior (number of pedestrians trapped in middle of road, abnormal running, and aborted crossing).

Countermeasures

Using these PMs, potential countermeasures were obtained using PEDSAFE, as shown in Table 8. Treatments that were selected using the project selection methodology are italicized.

Table 8. Countermeasures and Treatments Obtained Using PEDSAFE, Case Study 3

Type of Countermeasure	Treatments	Remarks
Pedestrian facility design	Improvements to street furniture	Not applicable (only in urban areas)
	Marked crosswalks and enhancements	
Roadway design	Curb radius reduction	
	Raised medians	May be possible with narrow lanes
Traffic calming	Curb extensions	Will intrude into motor vehicle lanes (can be provided when parking lane exists)
	Chokers	Insufficient right of way
	Crossing islands	No median present for installing island
	Landscaping	Not applicable (only in urban areas)
	Specific paving treatments	Colored/textured surfacing
Signals and signs	Signing	Existing in two approaches
	Pedestrian signals	
Other measures	*School zone improvements*	

Note: Treatments selected using PEDSAFE are italicized.

Selection of Safety Treatment

School zone improvements refer to a generic set of countermeasures involving providing separated walkways, appointing crossing guards to help children cross, installing school advance warning signs etc. Since this intersection is close to a school, these improvements are recommended.

Reducing the curb radius and providing marked crosswalks with specific pavement treatments are also recommended on approaches where they are not currently provided.

Case Study 4: Intersection of Hillsdale Drive and Greenbrier Drive

Hillsdale Drive extends between Rio Road and Greenbrier Drive and connects a number of residential and commercial establishments to U.S. Route 29. Hillsdale Drive also serves a large concentration of senior citizens. The Rivanna Trail encompassing Charlottesville has a spur that crosses Greenbrier Drive at this intersection.

The Thomas Jefferson Planning District Commission recently conducted a study[15] to assess the safety of pedestrians and bicyclists on Hillsdale Drive after the senior citizen community expressed concerns on the new developments proposed including an extension of Hillsdale Drive to connect with Hydraulic Road. The study concluded that a median island must be constructed, along with providing marked crosswalks and installing a three-way STOP sign at this intersection (see Figure 5).

Causal Factors

- Despite the presence of a bus stop near the intersection, no sidewalk is present on the south side of Greenbrier Drive. In addition, no sidewalk is present on the east side of Hillsdale Drive.

- Night-time lighting is not provided in and around the intersection.

- Sight distance for southbound traffic on Hillsdale Drive is limited because of the roadway geometry and vegetation.

- There are no “STOP” signs for left-turning traffic coming along Greenbrier onto Hillsdale. This situation might create conflicts for the pedestrians crossing Hillsdale close to the intersection.

- The crosswalk at Hillsdale is lengthy without any median islands. Senior citizens will find it difficult to use this crosswalk, especially since there are no stop signs for turning traffic and visibility is limited.

- The Rivanna Trail crosses Greenbrier east of this intersection. However, the crosswalk is located on the west end of Greenbrier, creating a detour for trail users. There are no warning signs or trail markings present at the trail intersection.

Based on these observations, the following causal factors were identified at this intersection:

- restricted pedestrian/bicyclist mobility and accessibility
- poor sight distance and visibility of bicyclists and pedestrians
- greater exposure levels of pedestrians and bicyclists.

Figure 5. Intersection of Hillsdale Drive and Greenbrier Drive (looking west)

Performance Measures

PMs associated with these causal factors are as follows:

- reduction in average crossing time
- pedestrian/bicyclist LOS
- reduction in average travel time to adjacent pedestrian/bicycle high-activity zones
- changes in crossing behavior (number of aborted crossings, dart-out first half)
- increase in pedestrians/bicyclists using the facility.

Countermeasures

Using PEDSAFE, countermeasures and treatments were obtained and are shown in Table 9. Countermeasures that were selected are italicized.

Table 9. Countermeasures and Treatments Obtained Using PEDSAFE, Case Study 4

Type of Countermeasure	Treatments	Remarks
Pedestrian facility design	*Sidewalks and walkways*	
	Transit stop treatments	
	Roadway lighting	
Roadway design	Curb radius reduction	
	Raised medians	May not be possible within available right of way
Traffic calming	Chokers	
	Crossing islands	
Signals and Signs	*Recessed stop lines*	
	Signing	

Note: Countermeasures that were selected are italicized.

Selection of Safety Treatment

Since this intersection is close to a Charlottesville Transit System (CTS) bus stop, specific treatments should be carried out to enhance the accessibility of the transit stop. Treatments recommended include providing sidewalks to reach the stop from all approaches, provide warning signs, and providing adequate lighting during the night-time hours.

Case Study 5: Mid-Block Crossing at Jefferson Park Avenue

The mid-block pedestrian crossing at Jefferson Park Avenue (JPA) (see Figure 6), adjacent to New Cabell Hall on the University of Virginia grounds, has been prone to a significant amount of collisions and near-misses. Students use this crosswalk to get to the adjacent parking lot. Currently, a ladder style crosswalk is marked and is supplemented with a "YIELD TO PEDESTRIANS IN CROSSWALK" sign that is installed at the centerline of the roadway.

JPA, one of the major arterials of Charlottesville, has moderate to heavy traffic throughout the day. Traffic flow is discontinuous because of the presence of a number of traffic signals near the hospital north of this crosswalk. The University Transit Service operates shuttle services along this route, and there are two UTS bus stops located on JPA approximately 100 ft to the west and 300 ft to the east of this location.

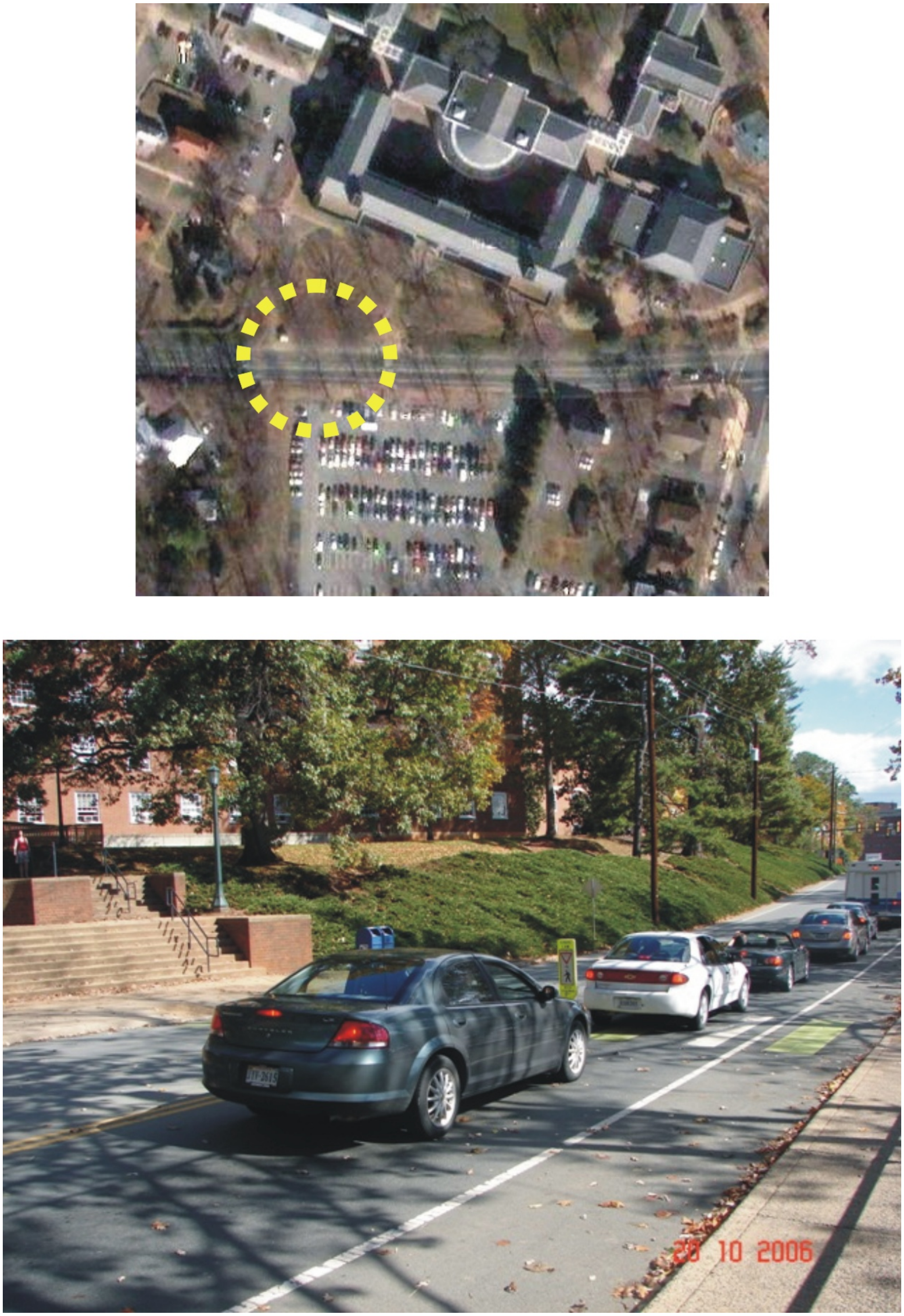

Figure 6. **Mid-block Crossing at Jefferson Park Avenue (facing east)**

Causal Factors

- Although many pedestrians use the crosswalk, there are many news reports of frequent dart-outs near this location by pedestrians.

- A striped bike lane is provided along JPA. No significant bicycle activity was observed during the observation period.

- The slow-moving traffic provided adequate opportunities for pedestrians to cross JPA. However, congested conditions resulted in vehicles having to stop frequently at the crosswalk.

- There is limited lighting at the crosswalk. Its effect on pedestrian safety could not be determined.

- Traffic volume in the eastbound lane is high and vehicles travel at low speeds. This creates an impression that pedestrians can cross safely at almost any time. But the westbound lanes have low traffic volumes, and vehicles are traveling at higher speeds.

- The westbound approach transitions from a single lane to a dual lane configuration at this crossing. This transition area creates confusion for pedestrians because although it may seem that all traffic has stopped, the outside westbound lane may still have moving traffic.

- Motorists' willingness to yield to pedestrians in the crosswalk was observed to decrease as congestion on JPA increases. Motorists tend to be less willing to make additional stops when they are caught in heavy congestion.

Performance Measures

PMs associated with these causal factors are as follows:

- high motor vehicle speeds
- high motor vehicle volumes
- greater exposure levels of pedestrians and bicyclists
- non-compliance of road users with traffic laws.

Countermeasures

Using these PMs, potential countermeasures were obtained using PEDSAFE and are shown in Table 10. Countermeasures that were selected are italicized.

Table 10. Countermeasures and Treatments Obtained Using PEDSAFE, Case Study 5

Type of Countermeasure	Treatments	Remarks
Pedestrian facility design	Improvements to street furniture	
Roadway design	Roadway narrowing	
	Lane reduction	
	Driveway improvements	
	Raised medians	Insufficient Right of way
Traffic calming	Curb extensions	
	Chokers	Insufficient right of way
	Speed table	
	Raised pedestrian crossings	
	Landscaping	
	Specific paving treatments	
	Crossing islands	Insufficient right of way
Signals and signs	Signing	

Note: Countermeasures that were selected are italicized.

Selection of Safety Treatment

At this location, a variety of countermeasures including roadway narrowing, raised pedestrian crossings, or paving treatments can be installed. However, considering the location of this crossing at the university area and the presence of a hospital close to the intersection, any raised feature on the pavement cannot be permitted because of the high volumes of rescue vehicles and ambulances. Hence, it is recommended that specific paving treatments be installed to enhance visibility of the crosswalk. Changing the vertical geometry of the road should also be explored. In addition, the additional westbound lane should transition sufficiently beyond the existing crosswalk to avoid conflicts.

Project Prioritization Example

The five case studies were considered for project prioritization. Table 11 demonstrates how this evaluation can proceed. A set of six prioritization criteria selected as appropriate from the list given earlier were used to compare the five case studies. These prioritization criteria were established based on the information available for each case study. More criteria can be used if warranted. Criteria could be given weights for prioritization.[7] However, since the table is only demonstrative, each criterion was equally weighted.

Each location was evaluated based on six PMs on a scale of 1 to 5: 1 for least preferred and 5 for most preferred. For example, the intersection of Alderman and McCormick has high pedestrian activity compared to the intersection of Hillsdale and Greenbrier; thus, the former was rated higher than the latter.

From the table, it can be seen that the mid-block crossing at JPA is highly favored for funding and implementation, and the intersection of Emmet Street and Morton Drive ranks last.

Table 11. Project Prioritization Example Using the Five Case Studies

Location/ Prioritization Criteria	Emmet and Morton	Alderman and McCormick	Whitewood and Hydraulic	Hillsdale and Greenbrier	Mid-block Crossing at JPA
Cost	1	3	2	5	4
Number of crashes	2	3	4	1	5
Proximity to high-activity zones	2	5	4	1	3
Ease of implementation and maintenance	1	2	4	3	5
Support from local community	1	3	5	2	4
Level of bicycle and pedestrian activity	2	5	3	1	4
Total	9	21	22	13	25
Ranking	5	3	2	4	1

CONCLUSIONS

- The gap between the state of the art and the state of the practice is considerable in the area of bicycle and pedestrian safety. Even though a variety of analytical tools and methodologies is available in the literature, they are seldom used in practice.

- Most of the cities and counties in this study do not follow a systematic procedure for identifying pedestrian and bicyclist hazardous locations. The countermeasures are installed more often as a reaction to a major conflict/crash or citizen complaints.

- Surrogate measures such as conflicts between pedestrians/bicyclists and motor vehicles are often used in pedestrian/bicycle safety analyses to identify hazardous locations and causal factors.

- To identify countermeasures, relevant PMs can be established based on hazards and causal factors. These PMs are also used to perform an evaluation of the safety treatment after implementation.

- The effectiveness of many bicycle and pedestrian safety countermeasures are not well established. Hence it becomes important that evaluation studies be performed after implementation of hazard mitigation projects to ascertain their effectiveness.

- Although the proposed framework developed in this study eliminates subjectivity to an extent, there are still some decisions that require sound engineering judgment and knowledge of the locality.

- The literature review shows that education, awareness, and enforcement are important components in any bicycle and pedestrian safety program.

RECOMMENDATIONS

1. *VDOT's BPS Program staff should adopt a systematic approach for identifying bicycle and pedestrian hazardous locations and selecting the appropriate countermeasures for implementation. Planners and engineers should adopt the proposed framework to determine countermeasures for remedying hazards to pedestrians and bicyclists.*

2. *VDOT's Bicycle and Pedestrian Coordinator and the BPS Program should ensure that all jurisdictions in Virginia are made aware of the state-of-art tools such as PBCAT, PEDSAFE, BIKESAFE and methodologies available for hazard identification, countermeasure selection, and evaluation.*

3. *VDOT's Traffic Engineering Division should modify VDOT's BPS Program according to the framework proposed in this study to analyze hazardous locations and generate potential countermeasures. The BPS Program's project selection and prioritization criteria should also be modified based on the framework proposed in this study.*

4. *VDOT's BPS Program staff should require applicants of the program to conduct evaluation studies of their projects post-implementation to refine the proposed framework for project selection and prioritization.*

5. *VDOT's Traffic Engineering Division, through the BPS Program, should conduct a study to assess the extent of the public's bicycle and pedestrian safety awareness. Enforcement issues should also be included. Based on the outcome of this study, campaigns should be conducted as a part of VDOT's BPS Program to educate users concerning bicycle and pedestrian hazards and involve the community proactively in bicycle and pedestrian planning.*

COSTS AND BENEFITS ASSESSMENT

Estimating the value of a decision-making tool is complex. Factors within the scope of this study, such as data requirements, contribute to the value of the tool. Factors beyond the scope of this study, such as the ease with which decision makers comprehend the tool's output and the expected political behavior of the stakeholders in the decision-making process, also contribute. Above all, the value that the tool can add to the decision-making process depends on how it is employed to improve current practices.

One way to illustrate the value that the prioritization process can add is to show that it promotes a more "effective" decision than would an alternative process (e.g., a random decision, or a decision based on only one or two criteria). For example, if the total weights and rankings in Table 11 are considered and it is assumed that a single project is to be selected for implementation, a decision based on only two of the six criteria discussed here might select any of the projects except (1) Emmet Street/Morton Drive and (4) Hillsdale/Greenbrier Drives, the outcome depending on which two criteria are used. A decision based on only one of the six criteria might select any of the projects except (1) Emmet Street/Morton Drive. A decision based only on other, extraneous factors that are not correlated with the criteria discussed here presumably might select any of the five projects.

Decisions based on two criteria run the risk that a project will be chosen that ranks as low as third out of five, admittedly a fairly close third, when assessed on the longer list of criteria. A decision process based on two criteria is already assured of delivering an outcome pretty close to the best possible outcome, so implementation of the more sophisticated prioritization can add a modest amount of value: the difference between 25 and 21 in the total weights. Decisions based on a single criterion run the risk that a project will be chosen that ranks as low as fourth out of five, a distant fourth, when assessed on the longer list of criteria. Decisions based on *no* relevant criteria run the risk of an even less favorable outcome, so the proposed prioritization can add even more value.

If it is assumed that that the proposed decision criteria are valid, then the comparison suggests that a decision based on the proposed prioritization process may be expected to be somewhat better than a decision based on only two of the six proposed criteria and appreciably better than a decision based on only one of the six or based on other, extraneous criteria.

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APPENDIX A

PEDBIKE SAFETY EVALUATION SURVEY SENT TO VDOT STAFF, SELECTED STATE DOTS, AND VIRGINIA CITY/COUNTY ENGINEERS AND MPOS

PedBike Safety Evaluation
Results Overview

Date: 5/29/2007 8:51 PM PST
Responses: Completes and Partials
Filter: No filter applied

Section I : General

Section II : Hazard Identification

6. How does your organization identify locations that are hazardous to bicyclists/ pedestrians (Check all that apply)?

Analysis of crash reports		9	60%
Policy initiatives		5	33%
Public hearings and workshops		8	53%
Input from interest groups/ other organizations		9	60%
Safety Audit/ Bicycle Compatibility Index/ Hazard Index		2	13%
Bicycle/ pedestrian Levels of Service		3	20%
Citizen complaints		11	73%
Others: Please Describe		8	53%

7. What information is collected/examined at these locations to determine the extent of the hazard (Check all that apply)?

Motor vehicle characteristics (volume, speed etc.)		11	73%
Crash characteristics (time, day of week, number of crashes, crash type, rate etc.)		9	60%
Roadway characteristics (class, lane width, configuration etc)		11	73%
Pedestrian/ Bicyclist characteristics (age, helmet usage, alcohol use, injury type, severity etc.)		6	40%

Conflicts with vehicles	9	60%
Other, Please Describe	7	47%

10. What engineering technique(s) do you use to validate whether a location is hazardous to bicyclists/ pedestrians (Check all that apply)?

Critical crash rate criterion	3	23%
GIS mapping and zonal analysis	6	46%
Pedestrian & Bike Crash Analysis Tool (PBCAT)	1	8%
Pedestrian Safety Guide & Countermeasure Selection System (PEDSAFE)	1	8%
Bicycle Countermeasure Selection System (BIKESAFE)	0	0%
Other, Please Describe	9	69%

Section III : Countermeasures Selection

11. Rate the following criterion based on the extent to which you consider them in the selection of a particular bicycle and pedestrian safety mitigation strategy.

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	Least Important	2	3	4	Most Important
Cost	0 0%	0 0%	6 50%	5 42%	1 8%
Construction time	2 17%	2 17%	8 67%	0 0%	0 0%
Ease of use	0 0%	1 8%	6 50%	4 33%	1 8%
Least disruption to existing traffic	0 0%	1 8%	6 50%	5 42%	0 0%
Availability of systems/equipment	0 0%	0 0%	9 75%	0 0%	3 25%
Ease of construction & maintenance	0 0%	0 0%	5 42%	5 42%	2 17%
Favorable public opinion	0 0%	1 8%	6 50%	4 33%	1 8%

Proven effectiveness of similar strategy implemented elsewhere	0 0%	0 0%	3 25%	4 33%	5 42%
Impact on crashes	0 0%	0 0%	2 17%	6 50%	4 33%

12. What is/are the most common type of PEDESTRIAN safety treatment(s) provided by your jurisdiction (Check all that apply)?

Traffic calming		8	57%
Mid-block crosswalks		2	14%
Intersection crosswalks		10	71%
Sidewalks		12	86%
Push button pedestrian signals		8	57%
Countdown pedestrian signals		6	43%
Pedestrian-only crossing signal cycles		2	14%
ITS-based (pedestrian detection, illuminated push buttons) measures		1	7%
Additional signing and/or pavement marking		9	64%
Overpasses/ Underpasses		1	7%
Other, Please Describe		3	21%

13. What is/are the most common type of BICYCLIST safety treatment(s) provided by your jurisdiction (Check all that apply)?

Bike paths, lanes, and/or wide curb lanes		10	71%
Additional signing and/or pavement marking		7	50%
Traffic calming		6	43%
Intersection improvements		2	14%
Other, Please Describe		2	14%

Section IV : Performance Measures

14. Does your organization evaluate the effectiveness of its pedestrian and bicycle hazard mitigation strategies ?

Yes		3	23%
No		10	77%
	Total	13	100%

If you answered "No" to the previous question, please skip the next question and proceed to question 16.

15. How often does your organization evaluate the effectiveness of completed bicycle and pedestrian safety treatments?

Within 3 months after implementation		1	17%
Between 3 and 6 months after implementation		0	0%
Greater than 6 months and up to 1 year after implementation		0	0%
Greater than 1 year after implementation		0	0%
Other intervals, Please Specify		5	83%
	Total	6	100%

16. What measures of effectiveness are used by your organization to determine the success/failure of a bicycle and pedestrian safety treatment (Check all that apply)?

Crash frequency and severity		5	45%
Degree of motorist, pedestrian and/or bicyclist compliance		4	36%
Number of conflicts		4	36%
Vehicle speeds		3	27%
Other, Please Describe		5	45%

17. Do you seek feedback from motorists, bicyclists and pedestrians after a safety treatment is implemented?

Yes		5	36%
No		9	64%

	Total	14	100%

If you answered "No" to the previous question, please skip the next question and proceed to question 19.

Section V : Prioritization

22. Does your organization utilize a system for prioritizing the allocation of funds for pedestrian and bike safety projects?

Yes		8	53%
No		7	47%
	Total	15	100%

If you answered "No" to the previous question, please skip the next question and proceed to question 24.

24. Typically, the amount of funds allocated by your organization towards pedestrian and bike safety projects every year is:

< $50,000		4	29%
$50,000 to $500,000		5	36%
$500,000 to $1,000,000		2	14%
> $1,000,000		3	21%

Section VI : Comments and Suggestions

APPENDIX B

PEDBIKE SAFETY EVALUATION SURVEY: ADVOCACY GROUPS

PedBike Safety Evaluation - Advocacy Groups

Results Overview

zoomerang

Date: 5/29/2007 8:52 PM PST
Responses: Completes and Partials
Filter: No filter applied

6. Please rate the following based on the extent to which they make WALKING unsafe

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	Least important	2	3	4	Most important
General design of the road	0 0%	0 0%	1 17%	3 50%	2 33%
Absence of sidewalks	0 0%	0 0%	2 33%	1 17%	3 50%
Lack of crosswalks	0 0%	1 17%	1 17%	3 50%	1 17%
Lack of pedestrian signals	0 0%	2 33%	1 17%	3 50%	0 0%
High speeds of motor vehicles	0 0%	0 0%	0 0%	2 33%	4 67%
Traffic volumes	0 0%	0 0%	3 50%	3 50%	0 0%
Motorists non-compliance of traffic signs and signals	0 0%	0 0%	2 33%	2 33%	2 33%
Lack of compliance by pedestrians	1 17%	3 50%	2 33%	0 0%	0 0%

7. Please rate the following factors based on the extent to which they make BIKING unsafe

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	Least Important	2	3	4	Most Important
General design of the road	0 0%	0 0%	0 0%	1 17%	5 83%
Lack of bike lanes/ crossings/ other facilities	0 0%	0 0%	2 33%	3 50%	1 17%
Motorist unwillingness to share the road	0 0%	0 0%	2 33%	2 33%	2 33%
Traffic volumes	0 0%	0 0%	4 67%	2 33%	0 0%
Motorists non-compliance of traffic signs and signals	0 0%	0 0%	2 33%	3 50%	1 17%
Lack of compliance by bicyclists	0 0%	3 50%	1 17%	2 33%	0 0%

11. Do you observe/ monitor any locations where the safety treatments are implemented to ensure that they achieve their purpose and objective?

Yes		2	33%
No		4	67%
	Total	6	100%

If you answered "No" to the previous question, please skip the next question and proceed to question 13.

12. If applicable, rate the following factors based on their significance in determining the effectiveness of bicycle and pedestrian safety treatments.

Top number is the count of respondents selecting the option. Bottom % is percent of the total respondents selecting the option.	Least effective	2	3	4	Most effective
Reduction in number of crashes	0 0%	0 0%	0 0%	1 50%	1 50%
Decrease in severity of crashes	0 0%	0 0%	1 50%	1 50%	0 0%
Degree of motorists compliance	0 0%	0 0%	0 0%	2 100%	0 0%
Number of near misses or conflicts	0 0%	1 50%	1 50%	0 0%	0 0%
Reduction in vehicle speeds	0 0%	0 0%	1 50%	0 0%	1 50%
Reduction in crossing time	0 0%	0 0%	0 0%	1 50%	1 50%
Increase in pedestrian/ bike activity at the location	0 0%	0 0%	0 0%	2 100%	0 0%
Reduction in public complaints	0 0%	1 100%	0 0%	0 0%	0 0%