Pedestrian and Bicyclist Intersection Safety Indices

Final Report

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Pedestrian and Bicycle Safety

Foreword

The primary objective of this study was to develop safety indices to allow engineers, planners, and other practitioners to proactively prioritize intersection crosswalks and intersection approaches with respect to pedestrian and bicycle safety. The models in this study use easily-collected, observable characteristics of an intersection to produce safety index values. Practitioners will be able to use these models on a small or large scale to determine where best to focus efforts to improve pedestrian and bicyclist safety.

Michael Trentacoste, Director
Director, Office of Safety
Research and Development

Notice

Quality Assurance Statement

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16. Abstract

The primary objective of this study was to develop safety indices to allow engineers, planners, and other practitioners to proactively prioritize intersection crosswalks and intersection approaches with respect to pedestrian and bicycle safety. The study involved collecting data on pedestrian and bicycle crashes, conflicts, avoidance maneuvers, and subjective ratings of intersection video clips by pedestrian and bicycle experts. There were a total of 68 intersection crosswalks selected for the pedestrian analysis from the cities of Philadelphia, PA; San Jose, CA; and Miami-Dade County, FL. The bicycle analysis included 67 intersection approaches from Gainesville, FL; Philadelphia, PA; and Portland and Eugene, OR.

Prioritization models were developed based on expert safety ratings and behavioral data. Indicative variables included in the pedestrian safety index model included type of intersection control (signal or stop sign), number of through lanes, 85th percentile vehicle speed, main street traffic volume, and area type. Indicative variables in the bicycle safety models (for through, right-turn, and left-turn bike movements) included various combinations of: presence of bicycle lane, main and cross street traffic volumes, number of through lanes, presence of on-street parking, main street speed limit, presence of traffic signal, number of turn lanes, and others. Through a user-friendly guide, practitioners will be able to use the safety indices to identify which crosswalks and intersection approaches have the highest priority for in-depth pedestrian and bicycle safety evaluations and subsequently use other tools to identify and address potential safety problems.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION AND BACKGROUND

There has been a pressing need for research to develop new tools to mitigate the loss of life resulting from pedestrian and bicyclist crashes with motor vehicles. National crash statistics for 2004 show that 4,641 pedestrians and 725 pedalcyclists were killed in crashes, accounting for approximately 13 percent of all traffic fatalities in the United States (NHTSA, 2004). In urban areas alone, these statistics can be much higher. Many injuries are not reported to recordkeeping authorities. A study by Stutts, et al. (1990) showed that less than two-thirds of bicycle-motor vehicle crashes serious enough to require emergency room treatment were reported in State motor vehicle files. Recent Highway Safety Research Center (HSRC) research for the Federal Highway Administration (FHWA) presented in *Accident Analysis and Prevention* corroborates such findings for both bicyclists and pedestrians (Stutts and Hunter, 1999).

Around 40 percent of pedestrian collisions occur at intersections and an additional 8 percent at driveway or alley intersections (Hunter, Stutts, Pein, and Cox, 1996). A variety of factors play a role, including pedestrian age, width of the crossing, street corners with large turning radii permitting higher motor vehicle speeds, and misunderstanding of pedestrian signals (Zegeer, 1991). Hunter, Stutts, Pein, and Cox (1996) also found that half of bicycle-motor vehicle collisions take place at intersections. Related factors include the age of the bicyclist, motor vehicle speeds and traffic volumes, provision of auxiliary right-turn lanes, and other designs that lead to weaving between bicycles and motor vehicles.

The objective of this study was to develop macro-level Pedestrian and Bicycle Intersection Safety Indices (Ped ISI and Bike ISI) that would allow engineers, planners, and other practitioners to use known intersection characteristics to proactively prioritize crosswalks and intersection approaches with respect to pedestrian and bicycle 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 priority for pedestrian and bicycle safety improvements 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.

CHAPTER 2. LITERATURE REVIEW

A number of studies and rating methodologies related to the safety of pedestrians and bicyclists have been conducted in recent years. A few studies have incorporated crash analyses to determine factors related to the risk level of pedestrians and bicyclists. Many others are primarily intended to indicate a compatibility level for pedestrians or bicyclists, also called “level of service” or “comfort level.” Compatibility refers to the characteristics of a road or intersection that make it attractive to pedestrian and bicyclist users. The studies listed below are separated into sections on:

- Bicyclist Compatibility.
- Bicycle Crash Analyses.
- Pedestrian Compatibility.
- Pedestrian Crash Analyses.

Since there are advantages to both of these types of methodology, there is a need to develop a safety-rating method that incorporates a variety of subjective user ratings, as well as more objective safety data such as evasive actions and crashes. Such a methodology would provide opportunities for State and local agencies to have a pro-active intersection rating tool; that is, they would be able to apply the “safety rating tool” to a large sample of intersections to identify sites with the greatest need for assessment. Thus, agencies could be pro-active in their approach without having to wait until pedestrian or bicyclist collisions occur before making the necessary improvements. The Ped ISI and Bike ISI developed in this research are intended to meet this need for a proactive approach.

BICYCLIST COMPATIBILITY

Botma (1995) proposed level of service (LOS) methodologies for bicycle paths and bicycle-pedestrian paths. Both methodologies defined LOS in terms of events: an event occurs when one user passes another user traveling in the same direction, or when one user encounters another user traveling in the opposite direction. As the number of users on a path increases, more events occur, or equivalently, more users experience hindrance from other users. As events become more frequent, the LOS deteriorates from A to F. This methodology addresses bicyclist (and pedestrian) crowding as reflected by passings and meetings on paths. It does not cover bicyclists’ perceived comfort and safety while riding in a motor vehicle environment (i.e., on the roadway).

Chapter 19 of the *Highway Capacity Manual* (2000) adopts Botma’s (1995) LOS methodology for exclusive and shared paths. Procedures are given for additional facility types. The LOS for on-street bicycle lanes is also dependent on the number of events, which vary according to the bicycle flow rate, mean speed, and standard deviation of the speed. At signalized and stop-controlled (on the minor street only, not all-way stop) intersections, the LOS depends on control delay. As delay length increases, the LOS deteriorates from A to F. For bicycle lanes on urban streets (intersections plus segments), the LOS depends on average bicyclist speeds.

Several models have been developed to relate roadway geometrics and operational characteristics to bicyclists’ perceived levels of comfort and safety (i.e., to measure bicycle compatibility). Because older models served as the starting point for newer models, this section is presented chronologically.

The Bicycle Safety Index Rating (BSIR) consists of two submodels, one for roadway segments and one for intersections (Davis, 1987). The safety of roadway segments depends on traffic volume, speed limit, outside lane width, pavement condition, and a variety of geometric factors. The safety of intersections is a function of traffic volume, type of signalization, and several geometric factors. BSIR values from 0 to 4 denote roadways that are extremely favorable for safe bicycle operation. On the other hand, roadways with BSIR values of 6 or above are questionable for bicycle operation. Despite its name, the BSIR does not incorporate any information about motor vehicle-bicycle crashes or conflicts.

In Broward County, FL, the BSIR was modified by placing greater weight on vehicle speeds and less weight on traffic volumes. The new model was called the roadway condition index (RCI) (Epperson, 1994). The RCI was then modified by placing less weight on pavement and location factors and by increasing the interaction between curb-lane width, speed limit, and traffic volume. The modified RCI was applied in Dade County, FL, as part of a multimodal evaluation of the county's transportation network.

Sorton and Walsh (1994) determined bicyclist stress levels as a function of three primary variables—peak-hour traffic volume in the curb lane, motor vehicle speeds in the curb lane, and curb-lane width. Secondary variables such as the number of commercial driveways were acknowledged, but were not included in the analysis because of funding limitations. Stress levels ranging from 1 (very low) to 5 (very high) were defined for values of each primary variable. For example, stress level 1 corresponds to a traffic volume of 50 or fewer vehicles per hour, 85^{th} percentile speeds of 40 kilometers per hour (km/h) or lower, and a curb-lane width of at least 4.6 meters (m).

The Intersection Hazard Score (IHS) was based on the RCI and other earlier models (Landis, 1994). It measures the level of hazard that bicyclists are likely to perceive while riding. The variables in this model included traffic volume, speed limit, outside lane width, pavement condition, and number of driveways. Despite its name, the IHS does not incorporate any information about crashes or conflicts.

A Bicycle Level of Service (BLOS) model for roadway segments was developed by having bicyclists ride selected roadway segments on a real-life course and provide comfort/safety ratings on a scale of A through F (Landis, Vattikuti, and Brannick, 1997). The presence of a stripe separating the motor vehicle and bicycle areas of an outside travel lane resulted in the perception of a safer condition than an outside travel lane of the same width, but without delineated motor vehicle and bicycle areas. The BLOS has many of the same variables as the IHS. The major difference is the inclusion of pavement condition as a variable in the BLOS, but not in the IHS. The BLOS also requires more detailed land-use information than the IHS.

Harkey, et al., developed a Bicycle Compatibility Index (BCI) for urban and suburban roadways at midblock locations (Harkey, Reinfurt, Knuiman, Stewart, and Sorton, 1998). Bicyclists watched a videotape of various roadway segments and provided ratings of how comfortable they would feel riding on each segment. The BCI was developed from those ratings. It incorporates variables that pertain to the "bicycle friendliness" of a roadway for an adult bicyclist. Examples of these variables are curb-lane width, traffic volume, and vehicle speeds. Many of these variables are also used in the BLOS. Unlike the BLOS, the BCI does not include pavement condition because pavement condition data would not be readily available. A key difference between the BCI and the BLOS is that the BLOS relied on bicyclists actually riding on the roadway, so their ratings pertain to how comfortable they actually felt. The video approach used to develop the BCI does not put bicyclists at risk and allows for a greater range of geometric and operating conditions than would be feasible on a real-life course. To verify the validity of this approach, a pilot study was conducted to compare bicyclists' ratings in the field versus their ratings from watching the video. The pilot study found that there was a reasonably good match between the two types of ratings.

The BCI values were then translated into bicycle level of service (LOS) designations (not to be confused with the BLOS model described above). LOS A (corresponding to a BCI < 1.50) indicates that a roadway is extremely compatible with (or comfortable for) an average adult bicyclist. At the opposite extreme, LOS F (corresponding to a BCI > 5.30) indicates that a roadway is extremely incompatible (or uncomfortable) for an average adult bicyclist.

Landis, et al., built upon the segment BLOS (Landis, et al., 1997) to develop an intersection BLOS (Landis, Vattikuti, Ottenburg, Petritsch, Guttenplan, and Crider, 2003). Data were obtained from bicyclists who rode through selected intersections and provided comfort/safety ratings on a scale of A through F. Roadway traffic volume, total width of the outside through lane, and the intersection crossing distance were found to be the primary factors influencing bicyclists' safety and comfort at intersections. The presence of a bike lane or paved shoulder stripe was not as important as it was in the BLOS for segments.

A Compatibility of Roads for Cyclists (CRC) index was created to evaluate routes in rural and urban fringe areas (Noël, Leclerc, and Lee-Gosselin, 2003). To develop the index, the authors surveyed cyclists to obtain: (1) their ratings of roadway segments, and (2) their perceptions of factors that affect the safety and comfort of cyclists. According to the survey results, cycling space and automobile speed received the greatest weights (30 and 20 out of a possible 100, respectively) in the index. Other index components are paved shoulders, automobile and truck traffic flows, sand/gravel/abundant vegetation, ditches, retail/industrial/residential entrances, curves and grades, and major junctions.

Hunter, Stewart, and Stutts studied the differences between bike lanes and wide curb lanes (Hunter, et al., 1999). They observed videotapes of nearly 4,600 bicyclists and evaluated operational characteristics and interactions between bicyclists and motorists. They found that bicyclist wrong-way riding and sidewalk riding were more common at wide curb lane sites. Also, traffic encroachment in adjacent lanes because of passing bicyclists was more common for wide curb lane sites. There was little difference between the types of bicycle facilities in the number or severity of the bicyclist-motorist conflicts observed. Overall, they concluded that the type of bicycle facility had much less impact on operations and safety than other site characteristics and recommended that both bike lanes and wide curb lanes be used to improve riding conditions for bicyclists.

The bicycle compatibility models reviewed here all relate various roadway and traffic characteristics with how comfortable bicyclists would feel riding along those roadway segments. Variables such as traffic volume and lane width were common to all of the models. The weights assigned to each variable differed among the models. Most of the data required by these models can be obtained easily. Some degree of subjectivity is involved in assigning values for the adjustment factors for pavement, location, etc. A greater degree of subjectivity is involved in classifying roads as being "good" or "bad" for bicycling on the basis of their BCI or other index ratings.

Most of the models described above are applicable to roadway segments (i.e., midblock locations). Several have an intersection component (BSIR, CRC Index, and intersection BLOS). None of the models incorporate information about crashes and conflicts. It is acknowledged that many locations have few or no crashes per year, so crashes would not be readily modeled. The collection of conflict data requires an intensive field effort, and few local traffic agencies have the staff resources to do so.

A logical next step would be to develop a model that incorporates information on the number and severity of motor vehicle-bicycle crashes, as well as conflicts and avoidance maneuvers, to roadway and traffic variables. Such a model would require exposure information for both vehicles and bicycles. Bicycle coordinators and traffic engineers could use such a model to establish priorities for needed intersection improvements where bicycle safety is a problem.

BICYCLE CRASH ANALYSES

Hunter, et al., performed a detailed analysis of 3,000 bicycle-motor vehicle crashes in California, Florida, Maryland, Minnesota, North Carolina, and Utah. Almost three-fourths of these crashes occurred at intersections, driveways, or other junctions (Hunter, Stutts, Pein, and Cox, 1996). Sixty percent of the crashes occurred on two-lane roads. Twenty-six percent occurred on roads with an outside lane width of less than 3.6 m (12 feet (ft)). Slightly more than three-fourths of the crashes occurred on roads with speed limits of 56 km/h (35 miles per hour (mi/h)) or less. Roads with narrower lanes and roads with higher speed limits were associated with more than their share of serious and fatal injuries to bicyclists.

The bicyclist and motorist were on parallel paths in 36 percent of the 3,000 crashes (Hunter, Pein, and Stutts, 1995). In another 57 percent of the 3,000 crashes, they were on crossing paths. Parallel-path crashes were most frequent when the motorist turned or merged into the bicyclist's path (34 percent of the parallel-path crashes) and when the motorist overtook the bicyclist (24 percent). Crossing path crashes were most frequent when the motorist failed to yield (38 percent of the crossing path crashes) and when the bicyclist failed to yield at an intersection (29 percent).

Wang and Mihan (2004) modeled bicycle-motor vehicle crashes at 115 signalized intersections in Tokyo, Japan. They classified crashes as BMV-1 (collisions between bicycles and through motor vehicles), BMV-2 (collisions between bicycles and left-turning motor vehicles), and BMV-3 (collisions between bicycles and right-turning motor vehicles). They then estimated the expected crash risk by developing negative binomial models for each crash type. The models contained different sets of explanatory variables, including traffic and bicyclist volume, intersection location, visual noise, pedestrian overbridges, and median width.

Before countermeasures to reduce bicycle (and pedestrian) crashes can be selected, an understanding of the events leading to these crashes is required. This process of determining the pre-crash actions is referred to as crash typing. The Pedestrian and Bicycle Crash Analysis Tool (PBCAT) is a software product intended to assist practitioners with improving bicycling and walking safety (Harkey, Mekemson, Chen, and Krull, 1999). PBCAT may be used to develop and analyze a database containing the crash types and other details of crashes between motor vehicles and bicyclists or pedestrians. The user can then access the countermeasure module to see what engineering, education, and enforcement treatments are appropriate.

Once bicycle crashes are crash-typed, appropriate countermeasures may be examined. BIKESAFE is an expert system that is currently being developed by the University of North Carolina HSRC as a counterpart to PEDSAFE (Hunter, Thomas, and Stutts, 2005). This system will provide users with information on how to improve bicyclist safety and mobility, with specific focus on crash types. BIKESAFE will be available on CD-ROM and online at www.walkinginfo.org/bikesafe. The online tools consist of a selection tool, interactive matrices, 50 countermeasure descriptions, and more than 50 case studies. With the selection tool, the user first selects either a performance objective or a prevalent crash type. Next, the user enters site characteristics. The expert system then develops a list of countermeasures that are appropriate for the situation. The user can read descriptions of each countermeasure and case studies in cities that have implemented the countermeasure. The interactive matrices allow the user to see at a glance which countermeasures are suitable to achieve each of 7 performance objectives or to address each of 13 crash types. BIKESAFE also contains information on understanding bicyclist crashes, implementing countermeasures, and creating a bicycling environment.

PEDESTRIAN COMPATIBILITY

Chapter 18 of the *Highway Capacity Manual* (2000) defines pedestrian LOS criteria for signalized and unsignalized intersections. These criteria are expressed in terms of delay (while pedestrians are waiting to cross the street) and space (at street corners and in crosswalks). The criteria include factors such as pedestrian volumes, crosswalk length and width, and cycle lengths. However, the criteria do not take into account actual or perceived safety and, therefore, do not incorporate other factors, such as crossing width or the number of turning vehicles.

Several authors have gone beyond the volume and capacity approach in the *Highway Capacity Manual* to include qualitative measures of pedestrian LOS. For example, Sarkar (1993) defined six pedestrian service levels. This qualitative scheme relied on subjective ratings of safety, security, comfort and convenience, continuity, system coherence, and attractiveness. Service Level A represents the most strongly pedestrian-oriented environments; the right-of-way is reserved exclusively for pedestrians. At the opposite extreme, pedestrian needs are totally disregarded under Service Level F.

Khisty (1994) proposed seven qualitative performance measures of pedestrian environments: attractiveness, comfort, convenience, safety, security, system coherence, and system continuity. The relative importance of each measure was determined from survey responses; security and safety were found to be the most important. Survey respondents also rated walking routes by assigning scores to these measures, on a scale of 0 (the worst, corresponding to LOS = F) to 5 (the best, LOS = A) according to their level of satisfaction. The overall score, and therefore LOS, of each walking route was the weighted average of the scores for the individual measures. The measures were not proposed specifically for intersections; the safety measure is perhaps the most relevant to intersections.

Nine evaluation measures (encompassing aesthetics, safety, and ease of movement) were used to analyze commercial areas and corridors in Winter Park, FL (Jaskiewicz, 1999). Each measure was scored from 1 (very poor) to 5 (excellent). The scores were averaged to obtain an overall LOS. Based on the analysis, specific pedestrian deficiencies were identified. Both short-term physical improvements and long-term design and policy solutions were recommended. This LOS approach does not address intersections directly; however, the physical components/condition measure includes one or more treatments at pedestrian crossings as a means of reducing vehicle speeds.

A number of researchers have developed models to measure the compatibility of roads for walking. These models relate geometric and operational features to pedestrian compatibility. Thus, data on lane widths, traffic volumes, and other features are needed to use these models. The text below describes several models.

The pedestrian environment factor model used in Portland, OR, includes four elements: (1) sidewalks, (2) ease of crossing streets, (3) street and sidewalk connectivity, and (4) terrain (1,000 Friends of Oregon, 1993). Taken together, these elements characterize the pedestrian friendliness of an area. Each element is scored on a 3-point scale and is equally weighted, so the pedestrian environment factor ranged from 4 points (lowest) to 12 points (highest). The advantage of the pedestrian environment factor is that engineers and planners can easily score a specific zone and see how pedestrian-friendly it is.

The Portland Pedestrian Master Plan describes two tools to prioritize pedestrian projects: (1) the Pedestrian Potential Index, and (2) the Deficiency Index (City of Portland, 1998). The Pedestrian Potential Index measures the strength of policy, proximity, and environmental factors that favor walking, whereas the Deficiency Index measures conditions such as missing sidewalks, difficult and dangerous street crossings, and lack of a connected street network. Difficult and dangerous street crossings were approximated by traffic speed, traffic volume, roadway width, and locations with motor vehicle-pedestrian crashes. The two indices can be used to identify areas where pedestrian facility improvements are most needed. The advantage of the Deficiency Index is that it relies on traffic, roadway, and crash data. These data are generally available, so engineers and planners can easily calculate deficiency indices and determine where improvements are most needed.

Dixon (1995) determined the pedestrian LOS for roadway segments by using facility continuity, conflicts, motor vehicle LOS, and other factors. An overall corridor score can be computed from the sum of the segment scores, adjusted for the lengths of each segment relative to the corridor length. The method was tested on five arterial roads and one collector road in Gainesville, FL, which resulted in LOS ratings of C, D, and E.

A more recent model defines pedestrian LOS as a function of outside lane width, shoulder or bike lane width, on-street parking, the planting strip, sidewalk presence and width, motor vehicle traffic volume and speed, and the total number of through lanes (Landis, Vattikuti, Ottenburg, McLeod, and Guttenplan, 2001). A roadway segment can be given a LOS rating ranging from A (best, when pedestrian LOS < 1.5) to F (worst, pedestrian LOS > 5.5). This model does not include intersections.

From the pedestrian's perspective, the maximum tolerable speeds of passing cars on three residential streets ranged from 51 to 58 km/h (32 to 36 mi/h) (Warren and Rousseau, 2002). These speeds were almost identical to the observed 85th percentile speeds. Most study participants judged speeds of up to 40 km/h (25 mi/h) to be reasonably or completely acceptable. They tolerated higher speeds 5 to k km/h (3 to 4 mi/h higher) when a wider planting strip or a greater street width was present, as these conditions placed them further away from moving traffic. Although limited in scope, this study gives useful information on pedestrian comfort levels with regard to speed and separation from traffic.

Gallin (2001) determined the pedestrian LOS by scoring and weighting a total of 11 design, location, and user factors. Integer scores of 0 to 4 are given to each factor, and the weights range from 2 to 5. For example, the "path width" factor is scored as 0 if no pedestrian path is present, 1 if the path width is 0 to 1 m, and up to a maximum of 4 if the path width is more than 2 m. Some factors are scored subjectively (such as "connectivity," which is 4 points if excellent, 3 points if good, etc.). Intersections and driveways are counted to assess the "potential for vehicle conflict" factor. The LOS ranges from A (ideal pedestrian conditions, total weighted score of 132 or higher) to E (unsuitable pedestrian conditions, total weighted score of 36 or lower).

A pedestrian LOS was developed for midblock crossings (Chu and Baltes, 2001; Baltes and Chu, 2002). Study participants observed midblock crossings for 3 minutes (min) and rated how difficult it would be for them to cross, on a scale of A to F. However, the participants did not actually cross streets, so their ratings pertain to how difficult it *would be* for them to cross, not how difficult it *was* for them to cross. The authors fitted a linear regression model using the ratings, geometric data, and operational data. It contained 15 variables related to traffic volumes, turning volumes, pedestrian age, vehicle speed, crossing width, presence of pedestrian signal, cycle length, and signal spacing.

A recent study in Sarasota, FL, made use of a large "Walk for Science" event to gather data from approximately 800 pedestrian participants on their perceived safety, exposure, and delay at intersection crossings (Petritsch, Landis, McLeod, Huang, and Challa, 2005). The resulting pedestrian LOS model had primary factors of right-turn-on-red volumes for the street being crossed, permissive left turns from the street parallel to the crosswalk, motor vehicle volume on the street being crossed, midblock 85th percentile speed of the vehicles on the street being crossed, the number of lanes being crossed, the pedestrian's delay, and the presence or absence of right-turn channelization islands.

When considering pedestrian facility compatibility, it should be noted that a high level of service (i.e., LOS A) does not necessarily indicate a safe or well-designed sidewalk or pedestrian facility. There may be few pedestrians using the facility, thereby producing a high level of service, but there may be negative design features that cause pedestrians to avoid the location.

There is still a need for research to understand pedestrian exposure and people's choices about where they walk.

PEDESTRIAN CRASH ANALYSES

A detailed analysis of 5,000 pedestrian-motor vehicle crashes in 6 States revealed that about one-half of these crashes occurred at either intersections or driveways (Hunter, Stutts, Pein, and Cox, 1996). Nearly 60 percent of the crashes occurred on two-lane roads. Almost three-fourths of the crashes occurred on roads with speed limits of 56 km/h (35 mi/h) or less. Serious and fatal injuries to pedestrians were directly proportional to the speed limit and number of lanes. Marked crosswalks were present in about 21 percent of crashes and pedestrian signals in about 7 percent. A sidewalk was present on at least one side in about 17 percent of the non-intersection crashes.

More than 44,000 pedestrian-motor vehicle crashes were reported in Florida from 1990 through 1994 (Baltes, 1998). With respect to age, pedestrians from ages 65 to 74 were at the greatest risk of being involved in a crash. They were also at the greatest risk of being injured or killed once involved in a crash. Pedestrians under age 19 were overrepresented in crashes while crossing not at an intersection, crossing at a midblock crosswalk, crossing at an intersection, and standing/playing in the roadway. Pedestrians from ages 25 to 34 were overrepresented in crashes while working on a vehicle in the road and while working in the road at other activities.

A study of motor vehicle-pedestrian crashes at signal-controlled urban intersections found that several operational variables were significant factors (Zegeer, Opiela, and Cynecki, 1985). Analysis indicated that pedestrian volume is the most important variable, followed by traffic volume. Each of these two variables showed a significant and positive relationship with the number of pedestrian crashes. After controlling for other factors, other variables that were overrepresented in pedestrian crash risk included two-way streets (compared to one-way), residential area types, wider streets, the presence of bus operations, and higher volumes of turning vehicles. Exclusive pedestrian signal timing was associated with a significantly lower pedestrian crash experience compared to concurrent timing at signalized intersections without pedestrian signals.

Another study examined the effects of marked versus unmarked crosswalks at unsignalized intersections, along with other factors, on the number of pedestrian crashes (Zegeer, Stewart, Huang, and Lagerwey, 2001). Traffic and roadway factors found to be related to a higher number of pedestrian crashes included higher pedestrian volumes, higher traffic volumes, and greater number of lanes. After controlling for other factors, speed limit was not significantly related to pedestrian crash frequency. The presence of a raised median (or raised crossing island) was associated with a significantly lower pedestrian crash risk on multi-lane roads.

Comparing marked versus unmarked crosswalks, there were no significant differences in pedestrian crash risk on two-lane roads. There were also no differences in crash risk for sites with or without marked crosswalks on multi-lane roads with traffic volumes of less than 12,000 vehicles per day. On multi-lane roads *without* raised medians and traffic volumes greater than 12,000 vehicles per day, locations with marked crosswalks had a higher pedestrian crash risk than locations with unmarked crosswalks. On multi-lane roads *with* raised medians and traffic volumes greater than 15,000 vehicles per day, pedestrian crash risk was higher at marked crosswalks than at unmarked crosswalks.

Many potential countermeasures were recommended to improve pedestrian safety related to crossing streets, instead of merely adding or removing a marked crosswalk. Improvements on multi-lane roads include adding pedestrian traffic signals (if warranted), installing raised medians or crossing islands, improving nighttime lighting, providing curb extensions, providing tighter intersection turning radii (to shorten crossing distances and lower the speeds of right-turning motorists), reducing the number of lanes, and/or providing advance stop lines (to improve sight distance between motorists and pedestrians in crosswalks). Recommended improvements on two-lane roads include narrowing travel lanes, removing parking near the intersection, improving lighting, adding signals (where warranted), and providing traffic-calming measures (on residential streets). Improved education and enforcement were also suggested to reduce certain types of pedestrian crashes.

A 2003 study evaluated the effect of a combination of intersection improvements on pedestrian crashes. A four-lane suburban roadway in central New Jersey was reconstructed to include redesigned intersections, a raised median, a narrower roadway width, re-timed signals, bike lanes, and sidewalks (King, Carnegie, and Ewing, 2003). The reconstruction resulted in a slight decline in 85th percentile vehicle speeds of 3 km/h (2 mi/h). Pedestrian exposure risk decreased by 28 percent. The effect on vehicle volumes was negligible. Using crash data from a 29-month period prior to reconstruction and previous research findings on crashes and speed, the authors projected that there would be four fewer vehicle-vehicle crashes per year. The reduction in crashes would result in a savings of $1.7 million over 3 years in crash-related costs. The annual number of crashes involving bicyclists and pedestrians was projected to remain the same.

The *Pedestrian Facilities User Guide—Providing Safety and Mobility* identifies which pedestrian-related facility improvements are expected to reduce pedestrian crashes for various crash types and roadway situations (Zegeer, Seiderman, Lagerwey, Cynecki, Ronkin, and Schneider, 2002). The User Guide also provides details of 48 different engineering improvements, including their purpose, the conditions when they are appropriate for use, considerations for use, and implementation costs. In addition, the countermeasure module of PBCAT shows the user details on which treatments are applicable to specific types of crashes (Harkey, Mekemson, Chen, and Krull, 1999). Pedestrian safety improvements from the User Guide and PBCAT will be adapted and expanded for application to intersection hazards.

The User Guide was updated and integrated into an expert system known as PEDSAFE (Harkey and Zegeer, 2004). This system provides users with information on how to improve pedestrian safety and mobility. PEDSAFE is available on CD-ROM and online at www.walkinginfo.org/pedsafe (accessed July 2005). The online tools consist of a selection tool, interactive matrices, 49 countermeasure descriptions, and 71 case studies of completed pedestrian safety improvements. With the selection tool, the user first selects either a performance objective or a prevalent crash type. Next, the user enters site characteristics. The expert system then develops a list of countermeasures that are appropriate for the situation. The user can read descriptions of each countermeasure and case studies in cities that have implemented the countermeasure. The interactive matrices allow the user to see at a glance which countermeasures are suitable to achieve each of 8 performance objectives or to address each of 12 crash types. PEDSAFE also contains information on understanding pedestrian crashes, implementing countermeasures, and creating a pedestrian environment.

CHAPTER 3. APPROACH METHODOLOGY

The development of the Ped ISI and Bike ISI in this study followed the basic steps listed below. These steps are described in detail in subsequent chapters.

- Select a group of study sites (Chapter 4).
- Gather data on intersection characteristics (Chapter 5).
- Gather data on safety at the study intersections (Chapter 5).
- Relate the intersection characteristics to intersection safety (Chapter 6).
- Produce indices for pedestrian and bicyclist safety at intersections (Chapter 6).

Each leg of an intersection can have different characteristics affecting pedestrian and bicyclist safety. Rather than rating the intersection as a whole, the Ped ISI and Bike ISI are intended to give an evaluation of the safety of a particular intersection leg—either a crosswalk in the case of pedestrian safety or an approach leg in the case of bicyclist safety. The core of the Ped ISI and Bike ISI development consists of four measures to gauge safety, illustrated in the concept of the pyramid shown in Figure 1:

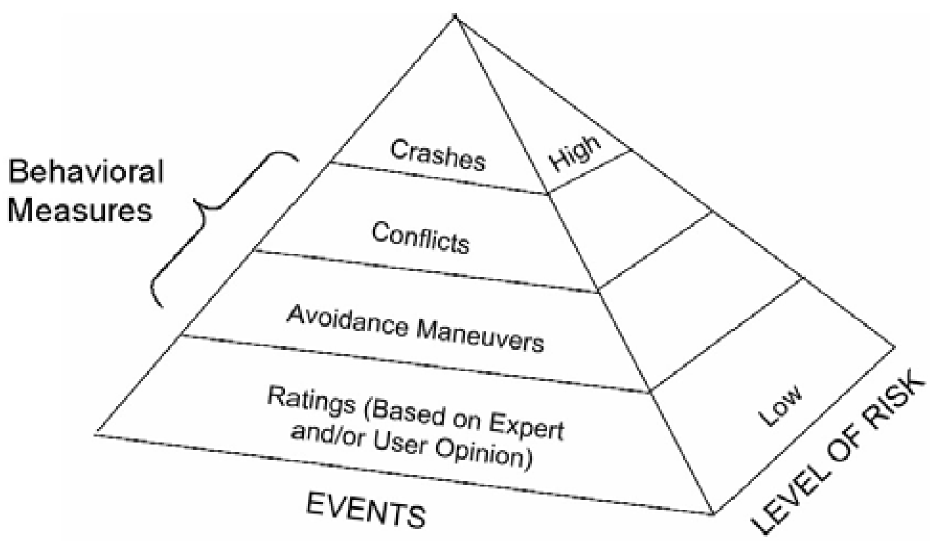


Figure 1. Hierarchical order of safety measures.

The top of the pyramid is *crashes*, the most objective indicator of safety. In reality, pedestrian- and bicycle-motor vehicle crashes are so sparse that only one or two per year may cause an intersection to be considered a "problem" or "high-crash" location. Thus, even using multiple years of data per site, it is difficult to base the identification of intersection safety problems solely on pedestrian or bicyclist crashes. Furthermore, bicycle and pedestrian crashes are very random and a location with a high pedestrian or bike crash potential may have zero crashes for several years.

The next two tiers comprise the behavioral-based safety data. The first of these two tiers is *conflicts*, defined as a *sudden* interaction between a bicycle or pedestrian and motor vehicle, such that at least one of the parties has to suddenly change speed or direction to avoid the other. Such interactions usually involve hard braking or swerving for the motorist or bicyclist or jumping or abruptly stopping by the pedestrian. The next tier in the progression is *avoidance maneuvers*, defined as *any* change in direction or speed caused by an interaction between parties. These interactions often involve slowing, soft stopping, or non-sudden changes of direction by motorists and bicyclists and non-sudden stopping or maneuvering around stopped vehicles by pedestrians. Although these behavioral data are not necessarily direct measures of site safety, they can often be used as surrogate measures of safety. There are several advantages to this approach. First, pedestrian and bicyclist conflicts and avoidance maneuvers occur more frequently than crashes and therefore can provide more data on the potential hazard of a site. Second, crash history for an intersection may not fully contain all of the crashes that occurred at the site, depending on the reporting practices of the local authorities. A behavioral observation can capture all occurrences within the observed time period and can distinguish between various types of pedestrian, bicyclist, and motorist behaviors. Third, this research is focused on the safety of a single intersection leg. This leg-specific approach requires precise and reliable location data that are not always available or easily attained from crash reports. Using crashes and behavioral measures together can serve to confirm the safety of a particular leg.

The base of the pyramid is intersection *ratings*, a subjective scheme to have experts, practitioners, and experienced users view pedestrian and bicycle facilities at intersections and rate them according to perceived risk or degree of safety. The safety rating that a site receives is very similar to a safety index—the intended result of this research.

It was expected that the Ped ISI and Bike ISI would be based on one or more of the safety measures described here.

CHAPTER 4. SITE SELECTION

An expert panel meeting was held in Chapel Hill, NC, on April 5–6, 2001, to gather opinions on the most important intersection factors that lead to safety problems for pedestrians and bicyclists. The panel consisted of selected State and local pedestrian/bicycle coordinators, local traffic engineers, FHWA division office representatives, the National Highway Traffic Safety Administration (NHTSA) liaisons to FHWA, and representatives familiar with the Americans With Disabilities Act. The panel focused primarily on developing a preliminary list of the most important intersection features associated with safety. The results of this meeting helped formulate the work plan and the proposed marketing plan. The panel members also provided input on potential cities for site selection.

HSRC staff visited candidate cities during the spring and summer of 2001 with the purpose of selecting three cities for pedestrian data collection and four cities for bicycle data collection. During the visits, HSRC staff met with the local pedestrian and/or bicycle coordinator or traffic engineer to learn about intersections with a suitable number of bicyclists or pedestrians, available crash data, and other characteristics of intersections that appeared to be good study sites.

Based on key factors such as amount and type of bicycling and walking facilities, number of bicyclists and pedestrians, willingness and eagerness of local contacts to participate, and windows of opportunity (i.e., climate) for videotaping, the following cities were selected as study locations.

Pedestrian Study Cities

- Miami, FL (23 sites).
- Philadelphia, PA (22 sites).
- San Jose, CA (23 sites).

Bicycling Study Cities

- Gainesville, FL (19 sites).
- Philadelphia, PA (21 sites).
- Portland, OR (13 sites).
- Eugene, OR (14 sites).

These locations included a diverse sample of intersections from the eastern and western parts of the United States, which represented a variety of intersection designs and traffic conditions for use in a comparative analysis. Philadelphia represented an eastern “grid” city and was used for both bicycling and pedestrian studies.

The objective in selecting sites from this set of cities was to select a variety of site conditions to fill a matrix of desired site characteristics. For pedestrian sites, these characteristics included:

- Type of traffic control (signalized versus stop sign).
- Number of travel lanes (two lanes, four lanes, etc.).

- Median type (undivided versus raised median).
- With and without on-street parking.
- A range of pedestrian volume and traffic volume.

For bicycle sites, these characteristics included:

- Traffic speed (high and low).
- Traffic volumes (high and low).
- Number of traffic lanes (two lanes and three or more lanes).
- Bike facilities (bike lanes, wide curb lanes, etc.).
- Right-turn lane design (shared or exclusive).
- Left-turn lane design (shared or exclusive).

An additional criterion was that selected intersections should have a sufficient amount of pedestrian or bicyclist traffic to allow for productive collection of observed behavioral data. Although it was clearly not possible to select all combinations of factors because of practical cost constraints plus the non-existence of certain combinations (e.g., very low traffic volumes with multi-lane signalized condition), the final site selection covered a good range of characteristics.

Each pedestrian site consisted of a crossing across a specific leg of an intersection. A bicycle site consisted of an approach to an intersection. At some intersections, two pedestrian crossings or two bicycle approaches were selected for data collection because each had different site characteristics; these counted as two sites. The final site selection consisted of 67 bicycle sites and 68 pedestrian sites.

CHAPTER 5. DATA COLLECTION

The collection of intersection data and the videotaping of sites were performed with the help of local data collectors in each city. The data collection effort was completed by reducing the video footage and gathering crash data on the sites. The following sections detail the process and results of the collection of physical characteristics, crash data, behavioral data, and subjective safety ratings.

PHYSICAL CHARACTERISTICS

Data were collected on the intersection geometry, traffic control, and facilities for pedestrians and bicyclists. These data were used in the regression analysis as objective, independent factors that would predict the safety index of an intersection. In addition to the variables listed below, a sketch of the intersection was made for each pedestrian and bicycle site to illustrate the intersection configuration. See Appendix A for the complete data collection forms and instructions. The following variables were identified by team members as having a potentially significant impact on pedestrian and bicyclist safety:

Pedestrian Study Site Variables

- Traffic control (presence and type).
- Traffic speed.
- Number of intersection legs.
- One-way or two-way.
- Number of lanes.
- Crossing width.
- Crosswalks (presence and type).
- Median islands (presence and width).
- Pedestrian signals (presence and type).
- Pedestrian-related signs.
- Right-turn curb radii.
- On-street parking.
- Right-turn-on-red allowance.
- Street lighting.
- Surrounding development type.

Bicycle Study Site Variables

- Traffic control.
- Number of intersection legs.
- One-way or two-way.
- Number of lanes.
- Crossing width.
- Crosswalks (presence and type).
- Median islands (presence and width).
- Right-turn curb radii sizes.

- On-street parking.
- Street lighting.
- Surrounding development type.
- Right-turn-on-red allowance.
- Sight distance.
- Number of driveways on main street.

CRASHES

The most commonly used measure of safety for a site is crash history. When dealing with intersections, crash data are normally gathered for the intersection as a whole. This research, however, required more specific crash data, since the base unit is a single crosswalk (for pedestrians) or a single approach (for bicyclists). Therefore, data were compiled for crashes occurring on or near the particular crosswalk or approach, rather than a total number for the intersection. Totaling crashes in this manner yielded data that corresponded to the particular crosswalk or approach.

State and city departments of transportation provided listings of crashes involving pedestrians or bicycles for each study site in their jurisdiction. In most cases, the accompanying crash information database did not have sufficient location information to pinpoint the position of the crash at the intersection. It was therefore necessary to obtain copies of the police-recorded crash reports and examine the sketch and narrative. Table 1 summarizes the crosswalk-specific and approach-specific crash data for pedestrian and bicycle sites. The crashes are noticeably few in number. Pedestrian and bicyclist crashes are rare events in general at a given location—made even rarer in this study since only a portion of the crashes at an intersection were considered.

Table 1. Summary of Crash Data

User	Number of Crossings or Approaches	Length of Data Collection Period	Total Number of Crashes Observed*	Crashes per Approach per Year		
				Average	Min	Max
Pedestrian	68	4 to 6 years	33	0.1	0.0	0.8
Bicycle	67	2 to 4 years	20	0.1	0.0	1.0

* Crash data were unavailable from the local agencies for five pedestrian crossings and one bicycle approach.

BEHAVIORAL DATA: CONFLICTS AND AVOIDANCE MANEUVERS

The behaviors of motorists, bicyclists, and pedestrians during interactions were studied in order to gather additional information on intersection safety. The behavioral safety measures used in this research were *conflicts*, a sudden action taken to avoid a collision, and *avoidance maneuvers*, any movement made because of an interaction between parties. These two behavior types were clearly distinguished for the bicycle study and therefore were analyzed separately; they were not as clearly distinguished for the pedestrian study and therefore were analyzed together as a combined group. This is discussed in detail below.

Data were collected by videotaping each site. Pedestrian and bicycle study sites were recorded for approximately 1 hour (h) 45 min each. Data collection was conducted on weekdays during daylight hours (i.e., 8:00 a.m. to 6:00 p.m.). Scheduling was done to avoid data collection during rain or extreme temperatures. An observer later watched the video and coded conflicts and avoidance maneuvers as they occurred. The study observed a total of 4,128 pedestrian events over 90 h and 3,831 bicyclist events over 129 h.

To collect data at pedestrian sites, the video camera was positioned on top of a stepladder in a location where the entire crosswalk could be viewed (Figure 2). Video footage was also taken parallel to the crosswalk to be used for the rating survey later.

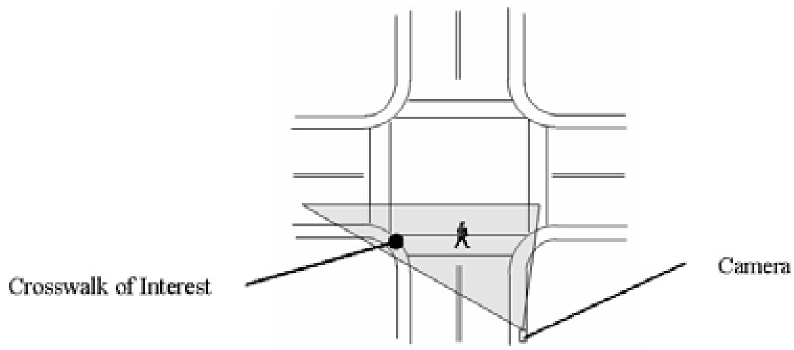


Figure 2. Video camera position for pedestrian data collection.

For bicycle sites, the video camera was positioned on a stepladder next to the roadway. The video camera was located across the intersection from the leg of interest (Figure 3). This position provided a view of the entire length of the leg of interest and allowed the bicyclists to be filmed as they came toward the camera. To provide video footage for those who would rate the safety of the intersection, additional footage was taken opposite the initial position to film in the direction of the bicyclists' travel. This position provided a more realistic viewpoint for the evaluators.

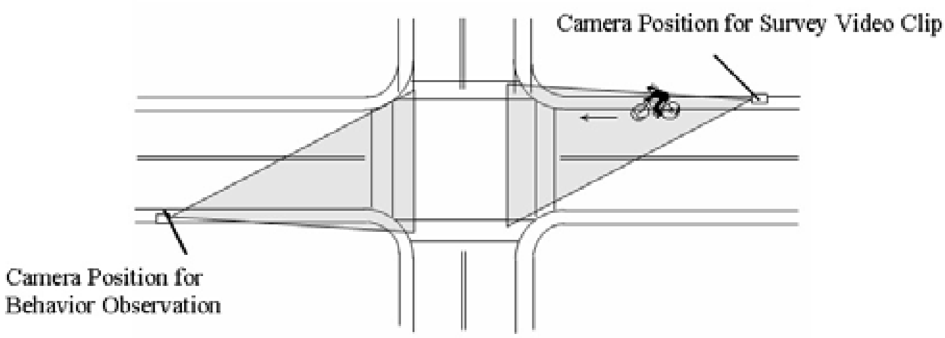


Figure 3. Video camera positions for bicyclist data collection.

Definitions of Conflicts and Avoidance Maneuvers

A conflict is a *sudden* change of direction or speed performed by either party in order to avoid a collision. This could include braking or swerving on the part of motorists and bicyclists. It is assumed that if one or both of the parties had not taken action, a collision would have occurred.

An avoidance maneuver is *any* change in speed or direction by a motorist, pedestrian, or bicyclist in response to the presence of another party. An avoidance maneuver is not necessarily a sudden movement and it is not necessarily assumed that a collision would have occurred had no action been taken. Examples of these are a pedestrian changing course to walk around a vehicle or a vehicle yielding to a crossing pedestrian.

While these definitions are clearly defined on paper, the classification of these interactions in the field is unclear at times, especially for interactions between pedestrians and motorists. The "traditional" definition of a traffic conflict involves a vehicle braking or weaving to avoid a collision. In past research, conflicts have sometimes been rated as mild, moderate, or severe, depending on the perceived nearness to a collision. Avoidance maneuvers are generally used to count "interactions" or observed behaviors that may be representative of safety or operational problems for the purposes of assessing locations and/or for evaluating roadway treatments.

Although conflict and avoidance measures have been used in traffic safety research and literature, no studies are known that have developed a clear relationship between pedestrian and bicycle crashes versus conflicts or avoidance maneuvers. While certain types of conflicts and avoidance maneuvers certainly indicate risky behavior or represent events that are similar to certain collision events, it can sometimes be difficult to clearly distinguish conflicts from avoidance maneuvers in terms of which events correspond to a greater risk of a pedestrians or bicyclist collision.

Since bicycles operate in a similar manner as vehicles (i.e., smooth rolling motion and faster speeds), it was reasonably clear to the observer when an interaction was a conflict or an avoidance maneuver. Thus, in the analysis and bicycle model development, these behaviors were analyzed separately. However, pedestrian interactions with motorists were more difficult to classify. For example, if a vehicle braked suddenly to avoid a collision with a pedestrian, the interaction would likely be classified as a conflict, since brake lights can be observed and the vehicle's change in speed is dramatic. On the other hand, if a pedestrian stops abruptly to avoid a vehicle, it is often more difficult to tell if the interaction could have led to a collision. Furthermore, it is not always clear whether a pedestrian is fully aware of an oncoming vehicle or narrowly avoided being struck. Given this fuzzy line between pedestrian conflicts and avoidance maneuvers, the two interaction types were grouped together as a single measure of safety in the analysis and pedestrian model development.

Pedestrian and Motorist Conflicts and Avoidance Maneuvers

Pedestrian events were watched for interactions between the crossing pedestrian and right-turning, left-turning, or through vehicles. Interactions with cross-street traffic were included in the observation. Right-turning vehicles included those turning right on red. The pedestrian study observed 911 motorist behaviors and 184 pedestrian behaviors. As discussed above, a behavior could be a conflict or an avoidance maneuver, since they were analyzed as a single group. The average rate, calculated on a per site basis, was 16.1 interactions per hour of observation. Table 2 and Table 3 display the types of interactions coded in the pedestrian study and the number of times each type was observed.

Table 2. Pedestrian conflicts and avoidance maneuvers.

Pedestrian Behavior	Number Observed
Stepped into roadway and then stepped back onto the curb to let vehicle pass (aborted crossing)	1
Went around vehicle that was blocking crosswalk	50
Hurried to avoid oncoming motorist	8
Stopped while crossing to let vehicle pass	125

Table 3. Motorist conflicts and avoidance maneuvers at pedestrian events.

Motorist Behavior	Number Observed
Right-turning motorist yielded to pedestrian	369
Left-turning motorist yielded to pedestrian	214
Through motorist yielded to pedestrian (unsignalized intersections only)	247
Right-turn-on-red (signalized intersections) or approaching motorist (unsignalized intersections) yielded to pedestrian*	81

* An approaching motorist at an unsignalized intersection was defined as a through motorist approaching the crosswalk from the far side of the intersection.

Bicycle Conflicts and Avoidance Maneuvers

Avoidance Maneuvers. The bicyclist study observed 1,898 avoidance maneuvers. Since it was possible that a bicyclist could be involved in more than one avoidance maneuver during their transit through the intersection, up to four avoidance maneuvers were coded for each bicyclist event. The average rate, calculated on a per site basis, was 18.6 avoidance maneuvers per hour of observation. For each avoidance maneuver, the observer noted the response of the bicyclist and the motorist separately. Table 4 and Table 5 display the types of avoidance maneuvers coded in the bicyclist study and the number of times each type was observed. These types of avoidance maneuvers were originally used in the study of bike lanes versus wide curb lanes (Hunter, et al., 1999).

Table 4. Bicyclist avoidance maneuvers.

Bicyclist Behavior	Number Observed
Stops pedaling	274
Slight change of direction	1054
Applies brakes	445
Major change of direction	75
Full stop	50

Table 5. Motorist avoidance maneuvers at bicyclist events.

Motorist Behavior	Number Observed
Slows	315
Slight change of direction	154
Applies brakes	139
Major change of direction	3
Full stop	32

Conflicts. Bicyclist events were watched for conflicts between the bicyclist and vehicles, pedestrians, or other bicyclists. During the 129 h of observation and 3,831 bicyclist events, 17 conflicts involving bicyclists were noted. Fifteen conflicts were bicyclist-vehicle conflicts, and two were bicyclist-pedestrian conflicts. See Appendix B for further information on these conflicts.

SAFETY RATINGS

In addition to objective measures of safety, this study sought to obtain evaluative measures of safety in the form of ratings. People who were knowledgeable in pedestrian or bicycle matters viewed the sites and gave ratings according to their perceived level of safety for a pedestrian or bicyclist. Similar to conflicts and avoidance maneuvers, these data can be collected relatively quickly and in large quantities. The following sections detail the process of creating the survey of sites and obtaining safety ratings from evaluators.

Survey Design

A survey was designed that would give evaluators enough information about the sites for them to provide safety ratings. The survey was designed as a Web site, where site data could be viewed and ratings could be submitted online. Given the need to distribute the survey to a large number of people around the Nation, an online format was determined to be the best format for the survey. Two Web sites were created—one for the pedestrian safety survey and one for the bicyclist safety survey.

The survey presented an illustration and a video clip for each site (Figure 5 and Figure 5, Figure 6 and Figure 7). The illustration showed basic intersection features such as sidewalks, crosswalks, bike lanes, traffic lane configuration, traffic control, and the direction of traffic flow. The video clip was designed to give the evaluator a pedestrian-eye view of the crosswalk or a bicyclist-eye view of the intersection approach. See Appendix C for more information on the survey Web site.

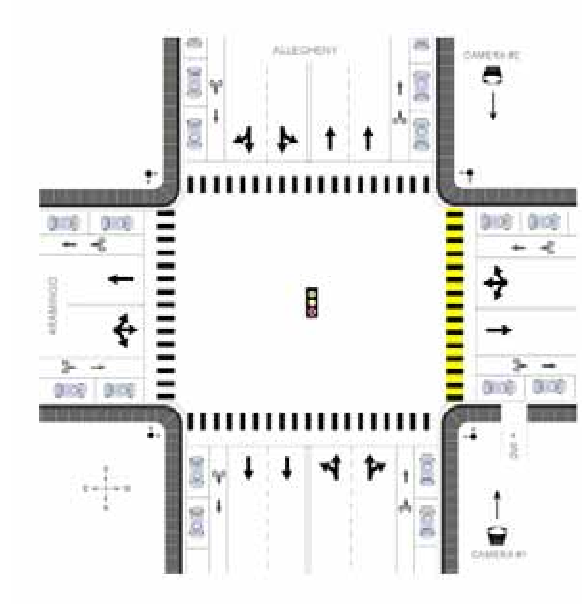


Figure 4. Illustration for pedestrian survey.

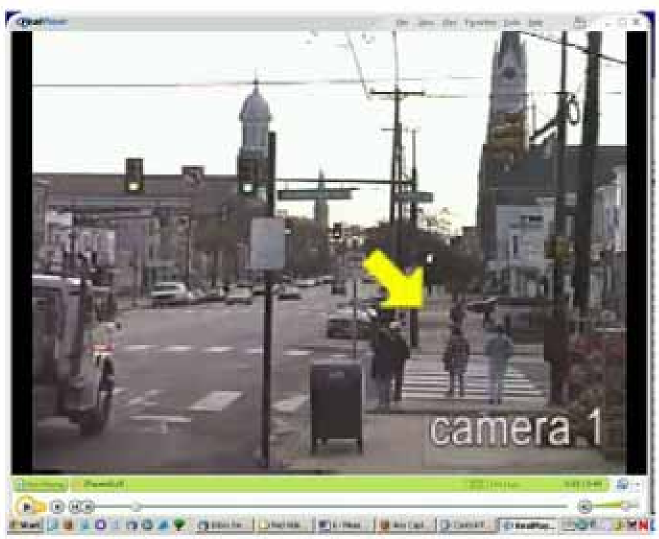


Figure 5. Video clip for pedestrian survey.

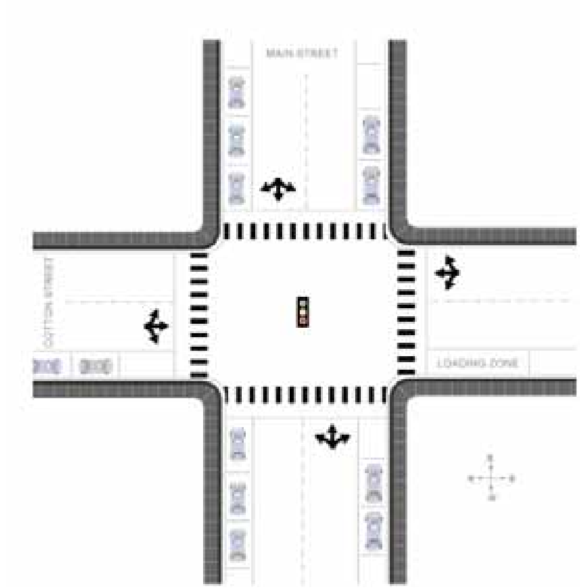


Figure 6. Illustration for bicyclist survey.

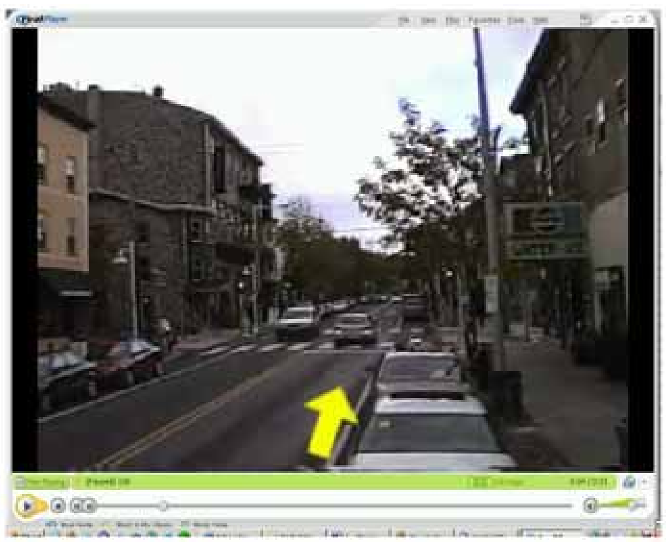


Figure 7. Video clip for bicyclist survey.

The video clips allowed evaluators to obtain a feel for traffic speeds and volumes, as well as other intersection features not displayed in the illustration. The ambient sound of the intersection was included in the video clip. The pedestrian survey consisted of 68 video clips that were 40 seconds (s) long. Each clip was composed of one or two camera angles, typically shot parallel to the crossing of interest (Figure 4 and Figure 5). A yellow arrow indicated the pedestrian crossing of interest. The bicyclist survey consisted of 67 video clips that were 30 s long. Each clip was composed of one camera angle, which was positioned on the leg of interest and pointed toward the intersection (Figure 6 and Figure 7). A yellow arrow was shown in the first 5 s of bicyclist video to indicate the direction that bicyclists would go. The number of vehicles shown in each clip was proportional to a 15-min vehicle count to ensure that a selected period did not show an abnormally high or low amount of traffic.

Evaluators were asked to view the illustration and video as if they were a pedestrian on the crosswalk or a bicyclist on the approach. They rated the sites on a scale of 1 to 6, according to their sense of safety and comfort. If the conditions were such that they felt very comfortable as a pedestrian or bicyclist and highly likely to walk or ride at the site, they were instructed to give a rating of “1”. If the conditions were such that they felt very uncomfortable as a pedestrian or bicyclist and highly unlikely to walk or ride at the site, they were instructed to give a rating of “6”. They were also given the option of “Not Enough Information” if they believed that they had insufficient information from the illustration and/or video to make an informed rating. Evaluators in the pedestrian survey gave one rating per crosswalk. Evaluators in the bicyclist survey gave separate ratings for each movement that a bicyclist could make at the intersection—through, right, and left.

The time needed to complete the surveys was approximately 2 h for the pedestrian survey and 2.5 h for the bicycle survey. Participants could take as much time as they wanted to rate each site, and the video clips could be replayed if needed. Several measures were taken to avoid survey bias. The research team did not want all evaluators to have the sites presented to them in the same order in case that would affect the ratings of the first few sites (because of unfamiliarity with the survey) or the last few sites (because of fatigue). Five different orders of sites were created to give each site an opportunity to be near the beginning, middle, and end of the survey order. The orders were assigned sequentially to evaluators so that there were equal numbers of evaluators for each order. The online format provided the option for evaluators to go back and redo previous ratings if they decided any particular rating had been incorrectly given (or needed an iterated revision). Because of the format of the survey, it is unknown how many evaluators revised earlier answers; however, this option was presented clearly in the instructions and was available on each rating page. The online design also allowed evaluators to logout and log back in later, thereby breaking up the survey into chunks instead of having to complete it all at once. See Appendix D for a summary of lessons learned by the research team in creating the online surveys.

Pilot Survey

The research team initially ran the pedestrian and bicyclist surveys as pilot tests using HSRC staff. Six sites were used for the pedestrian pilot survey and 15 sites were used for the bicyclist pilot survey. Feedback from these pilots indicated where additional information should be supplied to the evaluators and what technical issues (i.e., Web browser, streaming video player, etc.) might be faced by evaluators. Statistical analysis of the bicyclist pilot survey results revealed that left-turn ratings differed significantly from through and right ratings. This difference indicated that evaluators in the national survey should rate each movement separately.

Survey Audience

Survey participants were sought through announcements on various e-mail lists. The intended audience was composed of people who were experienced and knowledgeable about pedestrian or bicyclist matters. Table 6 and Table 7 show how the participating evaluators were related to pedestrian or bicyclist matters.

Table 6. Pedestrian survey participants.

Occupation or Relationship to Pedestrian Matters	N	Percent
Engineer	22	29
Planner	20	26
Ped/Bike Coordinator	13	17
Advocate for Blind and Visually Impaired	6	8
Other	5	7
Pedestrian Advocate	4	5
Ped/Bike Professional	4	5
Researcher	2	3
Total	76	100

Table 7. Bicyclist survey participants.

Occupation or Relationship to Bicycling Matters	N	Percent
Bicycling Advocate	54	38
Planner	27	19
Other	19	13
Ped/Bike Coordinator	19	13
Engineer	12	9
Ped/Bike Professional	7	5
Researcher	3	2
Total	141	100

As is seen in the tables above, survey participants came from a variety of fields. The majority of the pedestrian survey participants were engineers, planners, or ped/bike coordinators. Although blind and visually impaired pedestrians could not take the survey because of the illustration and video-based format, six participants were orientation and mobility specialists, who were instructed to take the survey with the concerns of blind individuals in mind.

A large portion of the participants in the bicyclist survey were those who described themselves as bicycling advocates. This generally meant that they cycled frequently and took part in organizations that advocated bicycling. The inclusion of these advocates was initially of concern because there might be some bias in advocate ratings. However, a statistical comparison of advocate ratings and non-advocate ratings showed that there was no significant difference between the mean ratings of both groups.

The survey was designed so that evaluators could stop whenever they chose, even if they had not given ratings to all of the sites. If an evaluator completed ratings for at least 10 sites, it was assumed that the evaluator had proceeded through enough sites to acclimate to the survey process and provide good data. There were 76 evaluators for the pedestrian survey and 141 evaluators for the bicyclist survey. Ratings from evaluators who completed fewer than 10 sites were discarded.

Ratings Data

Pedestrian sites received an average of 62 ratings each and bicycle sites received an average of 97 ratings each. The evaluators rated the sites on a scale of 1 through 6. Sites that were rated higher numerically were considered by the evaluator to be more uncomfortable and less safe than sites with low ratings. Table 8 shows the average rating and range of ratings for each group of sites. The average ratings for the sites varied between 2.0 and 2.8. The ranges of ratings spanned between three and four points on the scale, but the highest average rating was 5.1 for pedestrian sites and 4.4 for bicycle sites.

Table 8. Summary of site average ratings.

User	Average Rating	Range	Standard Deviation
Pedestrian	2.5	1.2–5.1	0.90
Bicycle through	2.1	1.3–4.3	0.56
Bicycle right turn	2.0	1.2–3.4	0.47
Bicycle left turn	2.8	1.5–4.4	0.71

The figures below show the distribution of ratings at each site group. The pedestrian sites in Figure 8 have the largest range of ratings and are the most spread out. This seems to indicate that there was a large range of opinions about the safety of crosswalks in contrast to the bicyclist site ratings, which are more tightly grouped. The bicycle through and right movements in Figure 9 and Figure 10 are grouped around the lower end of the ratings, whereas the left-turn ratings in Figure 11 are grouped in the middle of the scale and are slightly more diverse. Evaluators considered left turns generally less safe than a through or right movement and were slightly more varied in their opinions.

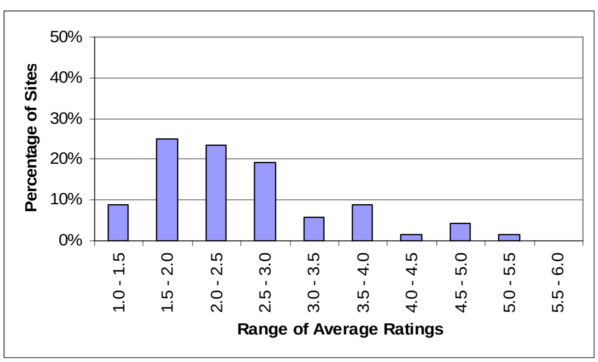


Figure 8. Ratings distribution at pedestrian sites.

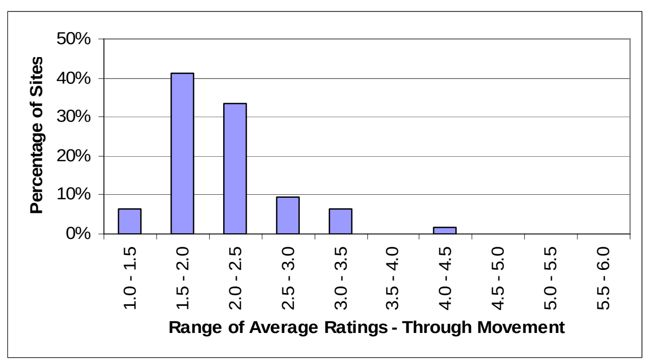


Figure 9. Ratings distribution for through movements at bicycle sites.

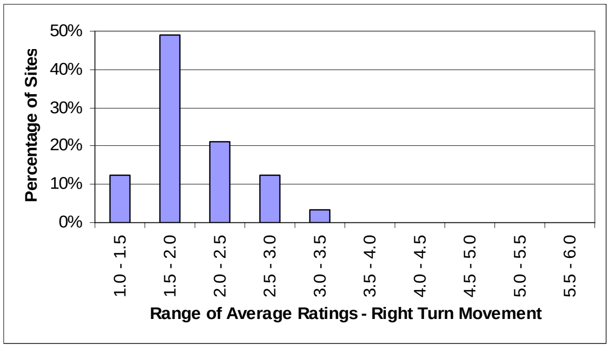


Figure 10. Ratings distribution for right turns at bicycle sites.

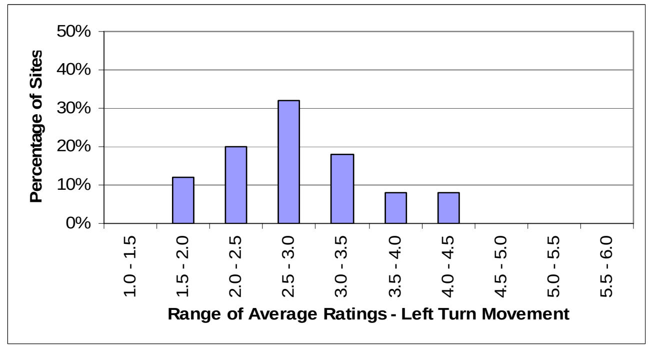


Figure 11. Ratings distribution for left turns at bicycle sites.

CHAPTER 6. STATISTICAL ANALYSIS AND MODEL DEVELOPMENT

Three types of safety measures were collected for use in the development of the Ped ISI and Bike ISI—crashes, behavioral data (conflicts and avoidance maneuvers), and subjective intersection ratings. Of these measures, models were developed for ratings and behavioral data. The small amount of crashes precluded any model development on crash data. Models based on ratings were developed using multiple linear regression, since the ratings generally followed a normal distribution. Models based on behavioral data were developed using a generalized linear model, since the behavioral data generally followed a Poisson distribution.

The ratings-based models served as the core of the development of the Ped ISI and Bike ISI. The fact that these models predict a safety rating for a site on a scale of 1 to 6 conveniently leads to the development of a safety index. While these ratings-based models were the base of the safety indices development, the behavior-based models also had contributions to the ISI. The analyst noted which variables were significant in the avoidance maneuvers model and the direction of their effect on safety (positive or negative). It was of interest to identify those roadway and traffic variables that were most strongly associated with the occurrence of conflicts and avoidance maneuvers. In some situations, variables that were significant in the behavioral model, but not significant in the ratings model, were retained in the ratings model. This approach reflects the methodology of using multiple measures of safety in the development of the Ped ISI and Bike ISI.

BIKE ISI DEVELOPMENT

The Bike ISI consists of three separate models that were developed to evaluate the safety of the three possible bicycle movements at intersections—through, right-turn, and left-turn. The primary data file used in developing these models was a site-oriented file where each site was a particular approach leg of a specific intersection. The data file contained a number of variables describing the roadway geometry, traffic control, motor vehicle traffic, and bicycle facilities associated with each intersection. Table 9 shows the variables considered for inclusion in the model development and the full range of their values.

Table 9. Variables used in bicycle analysis.

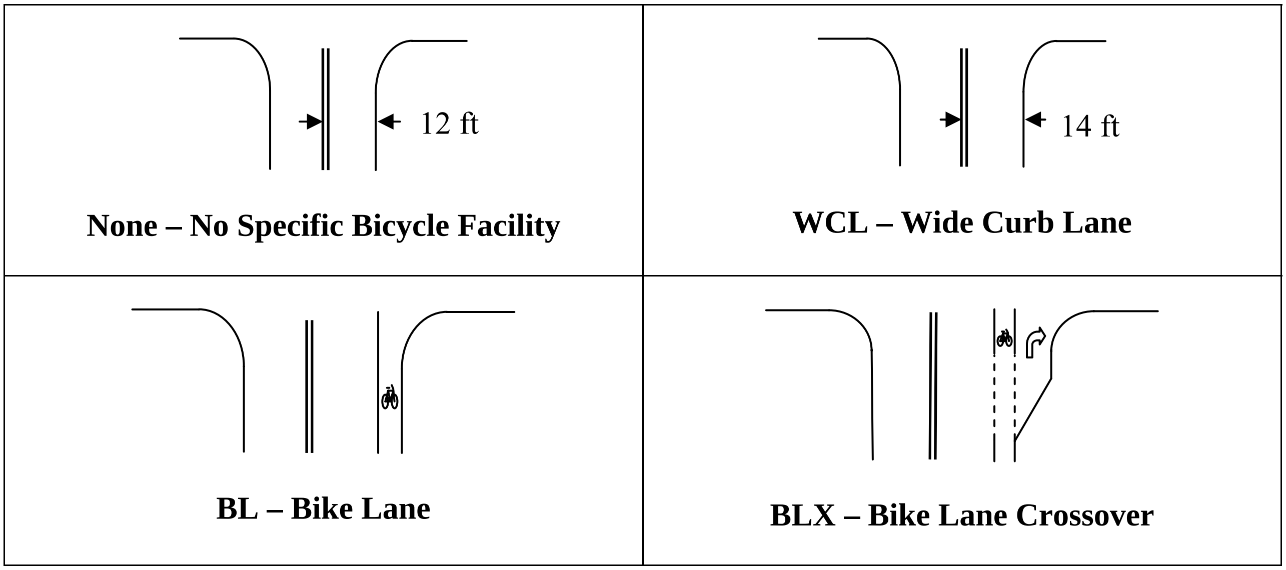
Description	Range in Study
Cross-street average daily traffic (ADT)	Counts in the thousands (1–36)
Main street ADT	Counts in the thousands (0.6–48)
Bicycle facility[1]	BL, BLX, WCL, NONE[1]
Number of driveways on approach	0, 1, 2, ….
Number of traffic lanes for cyclists to cross to make a left turn[2]	0–4
Number of left-turn traffic lanes on main street	0, 1, 2
Type of left turn allowed	Permissive, protected, both
On-street parking on approach	Yes, no
Turn radius on main street[3]	Large, small
Number of traffic lanes for cyclists to cross to make a right turn[2]	0–3
Number of right-turn traffic lanes	0, 1
Right-turn-on-red for main street	Yes, no
Traffic control on main street	Stop sign, signal, flashing red, none
Speed limit on cross street	24–72 km/h (15–45 mi/h)
Speed limit on main street	24–72 km/h (15–45 mi/h)
Turning vehicle traffic across the path of through cyclists[4]	Yes, no
Total through lanes on main street	0–3
Total through lanes on cross street	1–6

[1] See Figure 12 for bicycle facility illustrations.

[2] This variable assumes that the bicyclist is riding in a right-side or left-side bike lane or on the right-hand side of the road.

[3] Although turn radii were collected qualitatively, radii greater than approximately 8 m (25 ft) were considered to be large. Large radii allow for faster speeds from turning vehicles.

[4] This variable is "yes" if it would be reasonable to assume that the path taken by through cyclists *at the intersection* is regularly crossed by turning-vehicle traffic. A lack of turning traffic would occur with a bike lane crossover, since turning motorists would have merged already. It could also occur with one-way cross streets, if the one-way flow prevents motorists from turning in front of through bicyclists.



1 ft = 0.305 m

Figure 12. Bicycle facility types.

Ratings Models

Relationships between average ratings for the intersections and the variables listed in Table 9 were explored using various graphical methods, contingency tables, comparisons of means, and other methods to determine which variables were most strongly associated with the ratings. From these analyses, it could also be seen how best to categorize certain variables. For example, speed limits seemed most relevant when considered as two-level categorical variables indicating speed limits of 56 km/h (35 mi/h) or higher versus lower speed limits. Similarly, traffic control was used as a two-level variable indicating signalized intersections versus unsignalized intersections.

Statistical models for the average left-turn, right-turn, and through ratings were developed using regression analyses similar to those used in the development of the Bicycle Compatibility Index (Harkey, et al., 1998). These analyses lead to equations of the form:

$$I = b_0 + b_1x_1 + \ldots + b_kx_k \qquad (1)$$

where:

I = predicted safety index value for a given intersection.

$x_1, x_2, \ldots, x_k$ = variables or characteristics describing that intersection.

The $x_1, \ldots, x_k$ are the variables listed in Table 9, modifications of these variables, or interactions of these variables. In particular, some interaction terms arose because the effects of some variables seemed to differ when a bike lane was present versus when it was not. The coefficients $b_0, b_1, \ldots, b_k$ were estimated by a weighted least-squares procedure where each observation was weighted by the inverse of its variance. The resulting models are presented in the following tables.

The development of the ratings models went through an iterative process. For each version of a model, a comparison was made between the average evaluator rating given for a site and the rating predicted by the model. Sites with the greatest differences between the actual and predicted ratings were examined and reasons were found to explain most of the differences. Some differences were a result of factors that could not be incorporated into the model, since only one site of the group had the particular characteristic (i.e., high amounts of crossing pedestrian traffic, perpendicular on-street parking, high-speed channelized right-turn lane, etc.). Other factors did occur at enough sites to be added into the modeling process as separate factors. These factors included a more precise definition of the bike lane configuration (Figure 10), the number of vehicle lanes a bicyclist would cross to make a turn, and the presence of turning vehicles across a bicyclist's through movement. The resulting ratings-based models are presented below in Table 10 through Table 12

Table 10. Through-movement bicycle ratings model.

Variable No.	Variable Name	Estimate	T-Test	p-Value
0	Constant	1.130	12.71	<0.0001
1	Main street ADT	0.019	4.43	<0.0001
2	Main street speed limit ≥56 km/h* (≥35 mi/h)	0.734	4.17	<0.0001
3	Presence of turning-vehicle traffic across the path of through cyclists*	0.732	7.53	<0.0001
4	Vehicle right-turn lanes *and* bike lane present*	0.478	4.85	<0.0001
5	Cross street ADT *and* no bike lane	0.022	2.92	0.0051
6	Traffic signal *and* no bike lane*	0.412	3.52	0.0010
7	Parking on approach *and* no bike lane*	0.232	3.33	0.0312

R^2 = 0.79; dependent variable is the average numerical site rating.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Table 11. Right-turn bicycle ratings model.

Variable No.	Variable Name	Estimate	T-Test	p-Value
0	Constant	1.18	13.27	<0.0001
1	Main street ADT	0.025	6.51	<0.0001
2	Number of traffic lanes for right-turning cyclist to cross	0.496	4.64	<0.0001
3	Total through lanes on cross street	0.127	3.79	0.0004

R^2 = 0.67; dependent variable is the average numerical site rating.

Table 12. Left-turn bicycle ratings model.

Variable No.	Variable Name	Estimate	T-Test	p-Value
0	Constant	1.26	6.85	<0.0001
1	Main street ADT	0.027	2.91	0.0059
2	Bike lane (BL or BLX) present*	0.684	2.75	0.0090
3	Traffic signal*	0.520	3.62	0.0008
4	Main street speed limit ≥56 km/h (≥35 mi/h) *and* bike lane present*	0.658	2.61	0.0128
5	Number of traffic lanes for left-turning cyclist to cross *and* no bike lane	0.312	2.31	0.0259

R^2 = 0.79; dependent variable is the average numerical site rating.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Behavioral Models

For the analysis of behavioral data, a file was used that contained, for each bicyclist passing through the intersection, a count of avoidance maneuvers involving the cyclist and a motor vehicle, and the path taken by the cyclist (i.e., through, left, right). Unlike the pedestrian behavioral model, conflicts were not included in the bicycle behavioral model since there was a clearer distinction between bicycle conflicts and avoidance maneuvers. Appendix B contains information on observed bicycle conflicts.

The data file also contained the roadway and traffic variables listed in Table 9. Generalized regression models were used for these analyses where avoidance maneuvers were taken to follow a Poisson distribution with mean value μ such that the logarithm of μ could be expressed as a linear function of the roadway and traffic variables. The statistical significance of the estimated model coefficients thus determines which of the variables are associated with the likelihood of avoidance maneuvers between cyclists and motor vehicles. The resulting linear models, Tables 13 through 15, are displayed in the following tables in formats similar to the rating models in Table 10 through Table 12.

Table 13. Behavioral model for through bicyclists.

Variable No.	Variable Name	Estimate	X^2	p-Value
0	Constant	−1.89	268.31	<0.0001
1	Traffic signal*	0.306	10.99	0.0009
2	No bike lane (BL) or bike lane crossover (BLX)*	0.629	94.10	<0.0001
3	Total through lanes on cross street	0.312	24.92	<0.0001
4	Main street speed limit ≥56 km/h* (≥35 mi/h)	0.494	8.47	0.0036
5	On-street parking on approach*	0.649	104.46	<0.0001

N = 2,590 cyclists; dependent variable is the total number of motorist and bicyclist avoidance maneuvers.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Table 14. Behavioral model for right-turning bicyclists.

Variable No.	Variable Name	Estimate	X^2	p-Value
0	Constant	-1.58	50.46	<0.0001
1	Main street ADT	0.023	3.72	0.0537
2	On-street parking on approach*	0.538	7.09	0.007

N = 318 cyclists; dependent variable is the total number of motorist and bicyclist avoidance maneuvers.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Table 15. Behavioral model for left-turning bicyclists.

Variable No.	Variable Name	Estimate	X^2	p-Value
0	Constant	-1.46	34.84	<0.0001
1	Main street ADT	0.025	4.21	0.0402
2	On-street parking on approach*	0.598	10.67	0.0011
3	Total through lanes on cross street	0.203	6.53	0.0106
4	Traffic signal*	-0.539	4.95	0.0261

N = 267 cyclists; dependent variable is the total number of motorist and bicyclist avoidance maneuvers.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

While the linear models shown in Table 13 through Table 15 are models for the logarithm of the mean of the respective Poisson distributions, the interpretation of the algebraic signs of the coefficients is similar to that for the ratings-based models in Table 10 through Table 12. Namely, a positive sign indicates an increase in the likelihood of an avoidance maneuver, while a negative sign indicates a decrease.

Final Bike ISI Models

The final Bike ISI models were a combination of the ratings models and behavioral models. They were built using the ratings models as a basis, but were modified according to input from the behavioral models. On-street parking on the approach is an important variable with respect to both through and left-turn avoidance maneuvers, but is a factor with respect to the rating models only for through cyclists when no bike lane is present. Given that parking was significant for the behavioral model and is known by bicycle researchers to cause potential safety hazards, parking was included as a variable in the final bicycle models. A relatively small effect for parking was included in the left-turn model and through model by directly inputting the specific effect and re-estimating the other coefficients. There is no p-value for these parking variables since the effects were directly inputted. Table 16 and Table 17 show the final forms of the Bike ISI models.

Table 16. Final bike ISI models.

Movement	Model	R^2
Through	ISI = 1.13 + 0.019**MAINADT** + 0.815**MAINHISPD** + 0.650**TURNVEH** + 0.470(**RTLANES*BL**) + 0.023(**CROSSADT*NOBL**) + 0.428(**SIGNAL*NOBL**) + 0.200**PARKING**	$R^2 = 0.79$
Right Turn	ISI = 1.02 + 0.027**MAINADT** + 0.519**RTCROSS** + 0.151**CROSSLNS** + 0.200**PARKING**	$R^2 = 0.69$
Left Turn	ISI = 1.100 + 0.025**MAINADT** + 0.836**BL** + 0.485**SIGNAL** + 0.736(**MAINHISPD*BL**) + 0.380(**LTCROSS*NOBL**) + 0.200**PARKING**	$R^2 = 0.80$

Table 17. Variables used in bike ISI models.

Variable Name	Variable Description	Values
ISI	*Safety index value*	*Dependent variable*
BL	Bike lane presence[1]	0 = NONE or WCL 1 = BL or BLX
CROSSADT	Cross-street traffic volume	ADT in thousands
CROSSLNS	Number of through lanes on cross street	1, 2, …
LTCROSS	Number of traffic lanes for cyclists to cross to make a left turn[2]	0, 1, 2, …
MAINADT	Main street traffic volume	ADT in thousands
MAINHISPD	Main street speed limit ≥56 km/h (≥ 35 mi/h)	0 = no 1 = yes
NOBL	No bike lane present[1]	0 = BL or BLX 1 = NONE or WCL
PARKING	On-street parking on main street approach	0 = no 1 = yes
RTCROSS	Number of traffic lanes for cyclists to cross to make a right turn[2]	0, 1, 2, …
RTLANES	Number of right-turn traffic lanes on main street approach	0, 1, 2
SIGNAL	Traffic signal at intersection	0 = no 1 = yes
TURNVEH	Presence of turning-vehicle traffic across the path of through cyclists[3]	0 = no 1 = yes

[1] See Figure 10 for bicycle facility illustrations.

[2] This variable assumes that the bicyclist is riding in a right-side or left-side bike lane or on the right-hand side of the road.

[3] This variable is "yes" if it would be reasonable to assume that the path taken by through cyclists *at the intersection* is regularly crossed by turning-vehicle traffic. A lack of turning traffic would occur with a bike-lane crossover, since turning motorists would have merged already. It could also occur with one-way cross streets, if the one-way flow prevents motorists from turning in front of through bicyclists.

Bike ISI Adjustment Factors

Upon development of the Bike ISI, the research team compared the model-predicted rating for each site with the average rating it actually received in the survey. Some sites were found to have large differences between the predicted and actual ratings, most often due to a particular site characteristic that was not accounted for in the database. The rarity of these occurrences prevented an accurate modeling of their effect on the safety index value, but each characteristic was observed to have some negative effect on the rating of the site at which it was located (a negative effect on safety will increase the numeric safety index). While these factors are not included in the models, consideration should be given to sites with these characteristics with a view to modifying the model-predicted safety index value to account for the effect of these factors.

Adjustment Factors:

- Slip lane/channelized right-turn lane.
- Pavement irregularities (i.e., broken asphalt, trolley tracks, gutters/grates, etc.).
- High crossing pedestrian volume.
- Loading/unloading vehicles stopped in bicycle travel space.
- Bike lane to the right of an exclusive right-turn lane.
- Perpendicular on-street parking.
- Bus entering/exiting area where there is potential interaction with bicyclists.
- Offset intersection.
- Parking dimensions (i.e., width of parallel parking spaces, proximity of bike lane to parking).

PED ISI DEVELOPMENT

As with the Bike ISI, the Ped ISI was developed by using regression analysis to relate average rating scores and frequencies of conflicts and avoidance maneuvers to a number of variables describing the roadway geometries, pedestrian facilities, and motor vehicle traffic at those crossings. A list of these potential explanatory variables is shown in Table 18. For these analyses, the street being crossed is designated as the main street.

Table 18. Variables used in pedestrian analysis.

Description	Values
Main street traffic volume	ADT in thousands (0.6–54 in this study)
Main street speed limit	40, 48, 56, 64 km/h (25, 30, 35, 40 mi/h)
Traffic control on main street	Signal, stop, none
Total through lanes on main street	1–5
Number of right-turn traffic lanes	0, 1
Number of left-turn traffic lanes	0, 1
Crossing width	Width in feet (12–73 ft in this study, equivalent to 3.6–22.2 m)
Median island width	Width in feet (0, 3–25 ft in this study, equivalent to 0, 1–7.6 m)
Main street 85^{th} percentile speed	mi/h
Pedestrian signal	Yes, no
Crosswalk type	None, parallel lines, continental, other
Predominant area type	Commercial, office, mixed, residential

Ratings Model and Behavioral Model

Statistical models for average rating and behavioral data were developed in the same way as the Bike ISI. The main difference is that the bicycle behavioral model was based solely on avoidance maneuvers, whereas the pedestrian behavioral model is based on a combined group of conflicts and avoidance maneuvers. Results of these model developments are shown in Table 19 and Table 20.

Table 19. Pedestrian rating model.

Variable No.	Variable Name	Estimate	T-Test	p-Value
0	Constant	2.360	9.03	<0.001
1	Stop sign on main street*	−1.821	−9.81	<0.001
2	Signal on main street*	−1.830	−11.99	<0.001
3	Number of through lanes	0.368	8.76	<0.001
4	85^{th} percentile speed	0.018	2.47	0.0162
5	Commercial area*	0.221	2.39	0.197

R^2 = 0.84; dependent variable is the average numerical site rating.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Table 20. Pedestrian behavioral model.

Variable No.	Variable Name	Estimate	X^2	p-Value
0	Constant	−1.69	396.78	<0.0001
1	Signal on main street*	−0.689	86.75	<0.0001
2	Number of through lanes	0.337	87.11	<0.0001
3	Main street ADT	−0.016	12.65	0.0004
4	Median island*	−0.215	4.86	0.0274

N = 4,048 pedestrians; dependent variable is the total number of vehicle and pedestrian avoidance maneuvers and conflicts.

* Denotes an indicator variable where a value of 1 indicates that specified condition is true.

Both the ratings and behavioral models have "signal control" and "number of through lanes" as common variables. In fact, signal control shows up as the variable with the most effect on safety in both models. Stop sign control does not show up as significant in the behavioral model, possibly because of the low amount of vehicle traffic through stop-controlled intersections. Main street ADT is significant in the behavioral model, but not in the ratings model, probably because the 40-s video clip was too short to give the evaluator anything but a general idea of the amount of traffic. The negative coefficient of the main street ADT variable is most likely a result of its correlation with signal control and number of through lanes.

Final Ped ISI Model

All significant variables in the ratings model—signal and stop control, number of through lanes, vehicle speed, and commercial area type—were retained and included in the final Ped ISI model. The inclusion of traffic control types in the model assumes that the signal or stop sign is located according to normal traffic engineering practice (i.e., signal at multi-lane, high-volume intersections; stop sign for low-volume movements). Although the ratings model did not include a variable for traffic volume, such a variable was added to the final Ped ISI model because of its significance in the behavioral model. The traffic volume (main street ADT) is included as an interaction with signal control.

The commercial area showed up as a significant factor in the ratings model and was included in the final Ped ISI model. The surrounding area was considered commercial if the *predominant* land use consisted of restaurants, retail shops, gas stations, banks, etc. Although not completely intuitive by itself, this factor generally correlates with other characteristics, such as greater number of lanes, which warrant higher ratings from the evaluators. The authors recognize that modifying the land use around an intersection is not within the normal realm of countermeasures. However, since the goal of the Ped ISI is to prioritize sites according to pedestrian or bicyclist safety, it is important for the tool to reflect factors that indicate where safety improvement efforts should be focused.

Table 21. Final Ped ISI model.

Model	R^2
ISI = 2.372 – 1.867**SIGNAL** – 1.807**STOP** + 0.335**THRULNS** + 0.018**SPEED** + 0.006(**MAINADT*SIGNAL)** + 0.238**COMM**	$R^2 = 0.83$

Table 22. Variables used in Ped ISI model.

Variable Name	Variable Description	Values
ISI	*Safety index value (pedestrian)*	*Dependent variable*
SIGNAL	Traffic signal-controlled crossing	0 = no 1 = yes
STOP	Stop sign-controlled crossing	0 = no 1 = yes
THRULNS	Number of through lanes on street being crossed (both directions)	1, 2, 3, …
SPEED	85^{th} percentile speed of street being crossed	Speed in mi/h
MAINADT	Traffic volume on street being crossed	ADT in thousands
COMM	Predominant land use on surrounding area is commercial development (i.e., retail, restaurants, etc.)	0 = not predominantly commercial area 1 = predominantly commercial area

Ped ISI Adjustment Factors

Some of the bicycle study sites had characteristics that negatively affected the site rating, but were so rare that they could not be modeled. Suggested adjustment factors were included for the benefit of the practitioner. In contrast, the comparison of the predicted rating to the actual rating for pedestrian study sites did not reveal specific characteristics that could account for differences in the ratings. Because of the larger area that can affect a bicyclist's approach to an intersection and the three possible movements that a bicyclist can make, it is reasonable that a pedestrian crossing would have a simpler set of characteristics and have fewer characteristics that affect the safety of the crossing.

Somewhat surprisingly, the presence of a raised median was not found to be a significant factor in the results of the ratings or the avoidance maneuvers, even though past research has clearly found a significant safety benefit to pedestrians where raised medians or crossing islands are present on multi-lane roads. This may be explained by the fact that there were only 7 of 68 sites in the sample data where raised medians were present.

USING THE PED ISI AND BIKE ISI

This research report is accompanied by a User Guide, which succinctly presents the Ped ISI and Bike ISI and the data required to use them. It also contains several real-world examples where the Ped ISI and Bike ISI were used to determine safety index values for certain intersections.

DISCUSSION OF THE MODELS

The validity of the final Ped ISI and Bike ISI models may be judged largely by the variables included in the models and the known relationships between such variables and safety from what is known from previous safety literature.

Bike ISI Variables

- *Main street traffic volume*. Motor vehicle traffic volume on the main street appears in all three models. Logic would seem to indicate that the safety of an intersection would decrease with increased traffic volume in that more opportunities would be present for crashes, conflicts, and avoidance maneuvers between motor vehicles and bicycles. Traffic volume appears in various models developed to relate roadway geometrics and operational measures to bicyclists' perceived levels of comfort and safety (Davis, 1987; Epperson, 1994; Sorton and Walsh, 1994 (peak-hour traffic volume in the curb lane); Landis, 1994; Landis, Vattikuti, and Brannick, 1997; Harkey, Reinfurt, Knuiman, Stewart, and Sorton, 1998 (curb-lane volume); Landis, Vattikuti, Ottenburg, Petritsch, and Crider, 2003; and Noel, Leclerc, and Lee-Gosselin, 2003).

- *Main street speed limit ≥56 km/h (≥ 35 mi/h)*. The stopping distance for motor vehicles increases dramatically as a function of increased vehicle speed. Reaction time is also affected. Thus, main streets with higher speeds would make it more difficult for motor vehicle drivers to react to maneuvers by bicyclists and vice versa. Comfort and safety models with speed limit or motor vehicle speeds in the curb lane as a variable include Davis, 1987; Epperson, 1994; Sorton and Walsh, 1994 (vehicle speeds in the curb lane); Landis, 1994; Landis, Vattikuti, and Brannick, 1997; Harkey, Reinfurt, Knuiman, Stewart, and Sorton, 1998 (vehicle speeds in the curb lane); and Noel, Leclerc, and Lee-Gosselin, 2003.
- *Presence of turning-vehicle traffic*. Motor vehicles that turn across the paths of bicycles are a familiar crash type (Hunter, Stutts, Pein, and Cox, 1996). Bicycles are smaller than motor vehicles and thus not as visible. In addition, unless bicycles are a familiar part of the traffic stream, motor vehicle drivers may be more focused on obtaining a suitable gap in traffic to make the maneuver.
- *Number and presence of right-turn lanes on main street approach*. Once again, a familiar crash type is a motor vehicle driver making a right turn across the path of a through bicyclist (Hunter, Stutts, Pein, and Cox, 1996). This event often takes place soon after the motorist overtakes and passes the bicyclist. In the presence of right-turn lanes, recreational bicyclists going straight through the intersection may not properly position themselves to the left of right-turning motor vehicles. This can be particularly true with the presence of a bike lane, and especially if the bike lane is a solid stripe all the way to the intersection stop bar. Comfort and safety models with right-turn lanes as a variable include Davis, 1987, and Epperson, 1994.
- *Cross-street traffic volume*. This is an exposure variable, and the greater the cross-street traffic, the more likelihood of interactions with bicycles, especially if bicyclists violate a traffic signal or stop sign. However, there may be a threshold where traffic volume is great enough to prevent these violations by bicyclists.

- *Presence of a traffic signal at an intersection*. The presence of a traffic signal can indicate a greater chance of conflicts between bicyclists and motorists and can serve as a surrogate for turning-vehicle movements. Additionally, even though traffic signals are meant to create opportunities for opposing traffic flows, violation of the signal by either motor vehicle drivers or bicyclists can be problematic. Again, such actions are reflected by several crash types (Hunter, Stutts, Pein, and Cox, 1996). Davis (1987) included traffic signal presence as a variable in his comfort and safety model.
- *On-street parking on main street approach*. Presence of parking is included in all three models. The combination of the availability of parking and the presence of bicycles can lead to a variety of interactions, including motor vehicles pulling into and out of parking spaces, as well as a driver opening a door in the presence of a bicyclist. Bicyclists need to be out of the "door zone" when riding next to parked vehicles. Comfort and safety models with on-street parking as a variable include Davis, 1987; Epperson, 1994; and Harkey, Reinfurt, Knuiman, Stewart, and Sorton, 1998.
- *Number of traffic lanes for bicyclists to cross to make a right (or left) turn*. Sometimes a bicyclist must shift position between intersections to get in position to make a right turn. This maneuver can be particularly difficult if the bicyclist is riding in a left-side bike lane on a one-way street and needs to cross several traffic lanes to get to the other side of the street. The same would be true for the opposite situation, where the bicyclist has to cross several lanes to get in position to make a left turn. Recreational bicyclists may have difficulty moving appropriately from a bike lane to get in position for either a left or right turn. Comfort and safety models with number of lanes as a variable include Davis, 1987; Epperson, 1994; Landis, 1994; and Landis, Vattikuti, and Brannick, 1997.
- *Presence of a bike lane*. As discussed above, moving from the bike lane to a position to make a turn can be problematic. Comfort and safety models with bike lane presence as a variable include Davis, 1987; Epperson, 1994; and Harkey, Reinfurt, Knuiman, Stewart, and Sorton, 1998.

Thus, all of the factors included in the final bicycle safety index models have been found in other studies to be related to bicycle safety and/or have a logical association with safety. It could be argued that additional variables should or could also have been included in the model. However, no single analysis can necessarily identify all possible variables of importance due to sample size, site selection, and other such limitations in a macro-level analysis. Other factors known to be problems at intersections can be accounted for by the local practitioner in a more micro-level analysis.

Ped ISI Variables

- *Presence of traffic signals or stop signs*. Few, if any, formal studies have been conducted to quantify the effect of adding traffic signals or stop signs on pedestrian crash rates. However, traffic signals definitely change the interaction between motorists and pedestrians at intersections by creating gaps that allow for pedestrians to cross. Therefore, including information on such traffic controls at intersections would logically be an important factor in a pedestrian safety index. The fact that both signals and stop signs have the effect of reducing the crosswalk rating (indicating a safer crosswalk) is reasonable, since pedestrians would generally be safer in situations where traffic is controlled.

- *Number of through lanes on the street being crossed*. Recent research for FHWA found that pedestrian crash risk increases significantly as the number of travel lanes increases (Zegeer, et al., 2001). This is a logical relationship, since an increase in travel lanes at pedestrian crossings corresponds to an increase in the exposure distance and time that a pedestrian is in the street interacting with oncoming motor vehicles.
- *Vehicle speed (85th percentile speed).* The stopping distance for motor vehicles increases dramatically as a function of increased vehicle speed. In addition, the likelihood of a fatal injury to a pedestrian also increases greatly in a pedestrian collision with a motor vehicle for higher vehicle speed (United Kingdom, 1987). Therefore, including vehicle speed in the pedestrian safety index model is logical and appropriate. One disadvantage to using speed limit is that it is difficult to obtain from maps or speed limit signs. However, it was also thought that speed limit (which is easier to obtain) is often not a very good representation of actual vehicle speed at many locations. Therefore, it was decided to collect speed data on each of the approaches used in the pedestrian model development to more accurately represent the speed characteristics at each site. It is recognized that agencies that ultimately apply the pedestrian model will need to collect or obtain all of the input variables, including 85th percentile speed. However, if agencies do not have such data for certain sites, they have the option of adjusting the value of the speed limit by some amount (e.g., increasing by 14 km/h (9 mi/h)) to estimate 85th percentile speed value.
- *Main street traffic volume*. Increases in motor vehicle volume have been found to have a significant relationship with increased likelihood of pedestrian crashes (Zegeer, et al., 1985; Zegeer, et al., 2002). In both studies, increased traffic volume was one of the roadway factors that was most highly correlated with an increase in pedestrian crash frequency.
- *Commercial development*. The use of commercial area type in the model is possibly related to an increase in pedestrian exposure resulting from higher pedestrian volume and fewer pedestrian facilities. Past research has also found that commercial area was related to an increase in pedestrian crash risk (Zegeer, et al., 1985).

All of the factors included in the Ped ISI have been found in other studies to be related to pedestrian safety and/or have a logical association with safety. It could be argued that additional variables, such as "presence of raised medians," should also have been included in the model. However, no single analysis can necessarily identify all possible variables of importance due to sample size, site selection, and other such limitations. It is expected that the results of future pedestrian crash modeling (e.g., currently active project NCHRP 17-26) will be used to validate and enhance the Ped ISI.

COMPARISON OF SAFETY MEASURES

The methodology laid out in Chapter 3 describes how this research involved four measures of safety—crashes, conflicts, avoidance maneuvers, and safety ratings. An attempt to build a safety index model solely on any one of these safety measures would have certain drawbacks (Table 23). Thus, this research used multiple safety measures in the development of the Ped ISI and Bike ISI.

Table 23. Characteristics of pedestrian and bicyclist safety measures.

Safety Measure	Advantages	Disadvantages
Crashes	• Objective data. • Reflects factual measure of safety at an intersection.	• Rare events at a given site; could be misleading because of small numbers. • Modeling is difficult because of small crash sample size.
Behavioral Data (Conflicts and Avoidance Maneuvers)	• Observation-based (semi-objective) data. • Typically more numerous than crashes. • Quantity sufficient for analysis can be observed in a relatively short period of time.	• Somewhat rare events. • Relationship to crashes not clearly established. • Largely a function of exposure for some types of maneuvers.
Safety Ratings	• Ample data available. • Researchers can increase sample size as needed (add evaluators). • Expert opinion can identify important design elements independent of pedestrian, bicyclist, and vehicle traffic volumes.	• Subjective data. • Relationship to factual safety data unproven. • Ratings may focus on small-scale characteristics and overlook large-scale contributors such as traffic volume and pedestrian volume.

Combining these safety measures into one model is neither an easy nor clearly defined task. In this study, pedestrian crashes, bicycle crashes, and bicycle conflicts were few in number (Table 1), making it infeasible to perform detailed analyses on these data. Distribution differences between avoidance maneuvers (Poisson distribution) and ratings (normal distribution) did not allow for a simple combination of the regression results. In the end, the research team used the safety ratings data as the basis of the final Ped ISI and Bike ISI models and modified them according to the behavioral models.

The research team performed several tests to compare the four safety measures to each other for both the pedestrian and bicycle aspects of the study. This examination indicated how well the individual safety measures correlated with each other with respect to predicting the safety of a site. For the pedestrian ratings, sites were grouped into two or three categories based on each safety measure (i.e., sites with no crashes and sites with one or more crashes, etc.). Table 24 shows the results of categorical Chi-square tests performed between crashes, avoidance maneuvers, and ratings for the pedestrian analysis. There were no pedestrian conflicts to include in this comparative analysis. Results showed that crashes and avoidance maneuvers were not significantly different, but both measures were shown to be different from ratings. This difference might be explainable, since crash and avoidance frequencies are both likely related to traffic and pedestrian volumes, and therefore correlated with each other; on the other hand, ratings by observers focused on short (40 s) video clips of intersections where the raters saw the physical intersection features (e.g., number of lanes, presence of signal), but did not have time to gain a perspective on traffic (or pedestrian) volumes or speeds at the intersection.

Table 24. Comparison of pedestrian safety measures.

Safety Measure 1	Safety Measure 2	Statistical Test	p-Value	Related? (90% confidence)
Crashes	Conflicts/Avoidance Maneuvers	Chi-square test of independence	0.002	Yes
Ratings	Conflicts/Avoidance Maneuvers	Chi-square test of independence	0.118	No
Ratings	Crashes	Chi-square test of independence	0.169	No

For comparisons on the bicycle analysis, an overall intersection rating was calculated as an average of the ratings for the three movements, and these average ratings were compared across the safety measures (Table 25). For the 15 sites where at least one conflict was observed, the average overall rating was 2.36, while for the 52 sites having no conflicts, the average value was 2.23. These average ratings did not differ significantly ($p = 0.39$).

Similarly, the average overall rating for the 16 sites where at least one crash occurred was 2.35 versus an average of 2.23 for sites where no crashes were recorded. Again, the difference was not significant ($p = 0.39$). While the numbers of sites having crashes and conflicts were almost the same, these events generally did not occur at the same locations.

The comparisons displayed in Table 25 that involved crashes and conflicts were performed for the site as a whole, irrespective of the individual movements. The comparison of avoidance maneuvers to ratings, however, was performed separately for through, right-turn, and left-turn movements.

Table 25. Comparison of bicycle safety measures.

Safety Measure 1	Safety Measure 2	Statistical Test	p-Value	Related? (90% confidence)
Crashes	Ratings	Difference of categorical mean ratings	0.39	No
Conflicts	Ratings	Difference of categorical mean ratings	0.39	No
Avoidance Maneuvers (through movement)	Ratings (through movement)	Pearson correlation	0.26	No
Avoidance Maneuvers (right turns)	Ratings (right turns)	Pearson correlation	0.62	No
Avoidance Maneuvers (left turns)	Ratings (left turns)	Pearson correlation	0.09	Yes, but correlation was negative*

* The correlation coefficient was -0.24, indicating that left-turn avoidance maneuvers decreased (became more safe) as left-turn ratings increased (became more unsafe).

The comparisons shown in Table 24 and Table 25 indicate that the measures of safety used in this study did not generally relate well to each other with respect to predicting site safety, whether pedestrian crosswalk or bicycle approach. This is not altogether unexpected. These measures of safety are very different in what they measure. Also, two of them, crashes and conflicts, had very low numbers of observed events. Thus, the safety measures for which there are adequate data were avoidance maneuvers and ratings. The following list presents some discussion on the similarities and differences in these two safety measures.

Similarities Between Avoidance Maneuvers and Ratings

- It was observed that predictive models built on behavioral data and ratings had many variables in common (Table 10 through Table 15; Table 19 and Table 20). For the bicycle analysis, these variables were main street ADT, main street speed limit, traffic signal, and on-street parking. For the pedestrian analysis, these variables were traffic signal and number of through lanes. Considering the differences between these safety measures, this result is a good indication that these variables are important; thus, all of them were incorporated into the final safety index models.

Differences Between Avoidance Maneuvers and Ratings

- Avoidance maneuvers measured the interaction between pedestrians or bicyclists and vehicles. Although more interaction between pedestrians or bicyclists and motorists leads to greater exposure, these interactions are not necessarily unsafe. Ratings were expert opinions focused directly on evaluating the perceived safety of a site based on observed physical site characteristics. This inherent difference is perhaps one of the main reasons for differences observed between avoidance maneuvers and ratings as they relate to site safety.

- Each evaluator has assumptions about a site when providing a safety rating. If the assumed conditions are different from the actual conditions, then the result can lead to a disparity between ratings and avoidance maneuvers. For example, bicycling evaluators in this study were instructed to envision themselves riding on the street. At certain study sites, actual bicyclists were observed to ride mainly on the sidewalk, most likely because of high speeds, high traffic volume, or lack of a bicycling facility on the roadway. At these sites with the majority of bicyclists riding on the sidewalk, the ratings were *greater* than the average ratings of all sites; however, the avoidance maneuvers were *on par* with all sites. Presumably, this difference occurred because the evaluators envisioned themselves riding in the street (a more risky location that led to higher ratings), while actual bicyclists rode on the sidewalk (a safer location that led to few avoidance maneuvers). This situation demonstrates the type of disparity that can sometimes occur between ratings and avoidance maneuvers.

It is evident that these safety measures differ from each other in their inherent definition and in their predictions of pedestrian and bicyclist intersection safety. Given these differences, the research team hopes that the use of multiple safety measures resulted in a more comprehensive safety index model than relying solely on one safety measure.

DISCUSSION OF VARIABLE INCLUSION

The process used in developing the final rating models accounted for associations between the various independent variables. In other words, the model development was an iterative process that involved the development of hundreds of contingency tables to determine which variables were most highly associated with the safety ratings. For example, intersections in commercial areas were more likely to be signalized and also generally had a greater number of lanes when compared to locations that were not in commercial areas. However, even after controlling for the type of signal control and the number of lanes, the variable "commercial area" still contributed significantly to the prediction of the pedestrian rating more than the use of those other independent variables alone. Therefore, the variable "commercial area" was also included in the pedestrian rating model.

At each stage of the model building process, numerous contingency tables were examined and potential models were estimated. This iterative process involved exploring the influence of adding additional variables in terms of explaining the variation in pedestrian or bicycle rating values. Variables that contributed significantly to the predictive power of the model were included in the model.

ACCOMPANYING LOCAL FIELD STUDIES

This research sponsored two studies on a local level that paralleled the goals of this research. Both studies were conducted in Chapel Hill, NC, in April 2005. The participants in these studies were local residents who were either familiar with walking in the general environment (for the pedestrian study) or experienced bicyclists (for the bicycle study). None of the participants were professional engineers, planners, or ped/bike advocates. Although these studies were not true validation analyses of the safety index models (i.e., they did not test the tool itself), the smaller scale of these studies provided additional insight to the results of the safety index study.

Pedestrian Local Field Study

Ten pedestrian participants gave subjective safety ratings of 23 intersection crossings, once from viewing a video clip of each crossing and again after visiting the crossing in person. The objective of this study was to compare video safety ratings to onsite ratings.

Similar to the larger Ped ISI study, the unit of analysis was a single crossing instead of a whole intersection. Twenty-three crossings were chosen to represent a variety of crossing characteristics. Participants viewed a 30-s video clip of each crossing and gave a rating from 1 to 6, according to how safe they felt about crossing the street at that location. The participants were then taken to the sites in the field, where they viewed the crossing from the curb (did not cross) and again provided a safety rating for each crossing. For both types of ratings, participants provided comments on the factors that affected their rating decision.

Statistical comparison of the video versus field ratings did not show a significant difference between the two types of ratings (Table 26). This result is encouraging for the Ped ISI, which based models on video ratings. However, the limited scale of this local study should prevent overgeneralization of this result.

Table 26. Field versus video ratings for pedestrian local study.

	Paired Differences							
				95% Confidence Interval of the Difference				
(Participant's rating of video site) – (Participant's rating of site in person)	Mean	Std Dev	Std Error Mean	Lower	Upper	t	df	Sig. (two-tailed)
	0.078	1.146	0.076	−0.071	0.227	1.036	229	0.301

Bicyclist Local Field Study

Five bicyclist participants gave subjective safety ratings of 18 intersection approaches from a bicyclist's point of view, once from viewing a video clip of each crossing and again after visiting the crossing in person. The objective of this study was to compare video safety ratings to onsite ratings.

Similar to the larger Bike ISI study, the unit of analysis was a single approach instead of a whole intersection. Eighteen intersection approaches were chosen to represent a variety of approach leg characteristics. Participants viewed a 30-s video clip of each approach and gave a rating from 1 to 6, according to how safe they felt about approaching and traveling through the intersection at that location. The participants were then taken to the sites in the field where they viewed the sites (did not ride a bicycle) and again provided a safety rating for each approach. For both types of ratings, participants provided brief comments on the factors that affected their rating decision.

In the same manner as the development of the Bike ISI, the analysis was done according to the separate movements a bicyclist can make at an intersection—through, right, and left. Statistical comparison of the video versus field ratings was performed for each of these movements and for the intersection as a whole (Table 27).

Table 27. Field versus video ratings for bicycle local study.

Movement	Rating	Mean*	Pearson Correlation	P-Value From t-Test (two-tailed)	Sig. Difference at 95% Confidence?
All Movements	*Field*	2.17	0.63	0.11	No
	Video	2.07			
Through Movement	*Field*	1.96	0.52	0.37	No
	Video	1.87			
Right-Turn Movement	*Field*	1.79	0.61	0.01	Yes
	Video	1.59			
Left-Turn Movement	*Field*	2.77	0.57	1.00	No
	Video	2.77			

* Analysis is based on 5 evaluators rating 18 sites.

The analysis did not show a significant difference between field and video ratings for the through and left movements, as well as all movements averaged together at each intersection. There was a significant difference for the right-turn movement. The results of this analysis seem to indicate that field ratings will parallel video ratings for the majority of the study; however, there is some question about their association for right-turn ratings. However, low numbers of participants makes it difficult to generalize the findings of this local study. Recommendations are provided in Appendix D for conducting future online video surveys.

CHAPTER 7. CONCLUSIONS AND DISCUSSION

The pedestrian and bicycle intersection safety indices developed in this study are intended to prioritize intersection crossings (Ped ISI) or intersection approaches (Bike ISI) according to the relative level of safety for pedestrians or bicyclists given macro-level site characteristics. The analysis incorporated behavioral data in the form of conflicts and avoidance maneuvers and subjective data in the form of expert safety ratings. The final models are shown below in Table 28 and Table 29. For an explanation of the variables, see Table 17 on page 35 and Table 22 on page 39.

Table 28. Bicycle intersection safety index (Bike ISI).

Movement	Model
Through	ISI = 1.13 + 0.019**MAINADT** + 0.815**MAINHISPD** + 0.650**TURNVEH** + 0.470(**RTLANES*BL**) + 0.023(**CROSSADT*NOBL**) + 0.428(**SIGNAL*NOBL**) + 0.200**PARKING**
Right Turn	ISI = 1.02 + 0.027**MAINADT** + 0.519**RTCROSS** + 0.151**CROSSLNS** + 0.200**PARKING**
Left Turn	ISI = 1.100 + 0.025**MAINADT** + 0.836**BL** + 0.485**SIGNAL** + 0.736(**MAINHISPD*BL**) + 0.380(**LTCROSS*NOBL**) + 0.200**PARKING**

Table 29. Pedestrian intersection safety index (Ped ISI).

Model
ISI = 2.372 – 1.867**SIGNAL** – 1.807**STOP** + 0.335**THRULNS** + 0.018**SPEED** + 0.006(**MAINADT*SIGNAL)** + 0.238**COMM**

APPLICATION OF THE PED ISI AND BIKE ISI

The Ped ISI and Bike ISI are intended to be used to give relative rankings of intersections according to pedestrian and bicyclist safety. The intent of this tool is **not** to dictate a pre-determined index value that would warrant safety improvements. Rather, the Ped ISI and Bike ISI provide the practitioner with a way of prioritizing a group of intersections according to the relative likelihood of safety for pedestrians and bicyclists. This prioritization approach will allow practitioners to target the most hazardous sites, but also work within the confines of budgetary restrictions.

The authors envision practitioners using the Ped ISI and Bike ISI to evaluate each approach or pedestrian crossing at all intersections in their jurisdiction or a select group of intersections. The tool and accompanying instructions is laid out in an easy-to-use format in the accompanying User Guide, which provides several real-world examples and Quick Reference Tables for safety index values. Once safety index values are assigned to each site, the practitioner would then select the sites with the highest index values and conduct more detailed reviews of those sites (using other tools and methods) to determine whether any geometric or traffic control treatments are needed to improve the safety of the intersection. The User Guide recommends resources such as PEDSAFE and BIKESAFE to aid with countermeasure selection (Harkey and Zegeer, 2004; Hunter et al., 2005).

GEOGRAPHICAL RELEVANCE OF THE MODELS

The Ped ISI and Bike ISI were each developed based on sites selected from three cities representing three geographic areas, including West Coast (Oregon and California), Northeast (Philadelphia), and Southeast (Florida). Data were not collected in other States or regions of the United States, since the scope and resources for this study were limited because of the large amount of data collected at each site. Also, sites were selected to represent some of the more common characteristics of intersections, and it was not practical to include sites covering all possible site conditions; State practices; regions of the United States; or demographics of drivers, pedestrians, and bicyclists. However, this study does include consideration of hundreds of hours of video data collection at approximately 150 intersections in several States, as well as intersections ratings by pedestrian and bicycle professionals throughout the United States. It is expected that pedestrian and bicycle safety information from future studies might be useful to refine the models and index procedure developed herein.

LIMITATIONS OF THE RESEARCH

Although the sites used in this study varied in their geometric and traffic characteristics, there is concern that the site selection did not include the most hazardous intersections in the study cities. The results of the safety survey seem to indicate that the sites in the study did not cause the evaluators to use the full range of the 6-point scale (very few 5's and 6's). This result is probably a result of the site selection process. This study depended on finding sites with at least moderate amounts of existing pedestrian or bicyclist traffic in order to collect sufficient conflict and avoidance maneuver data. In general, users are more likely to choose easier, safer sites to walk or bicycle rather than difficult ones, and, therefore, it was difficult to find high-hazard sites (i.e., ratings of 5 or 6) that also carried many travelers on foot or bike. The development of the 6-point scale in this study still allows for those sites with higher hazard levels (5's and 6's) to be found and rated when this safety rating is applied to urban and suburban intersections. Additionally, since the avoidance maneuvers, conflicts, and safety ratings were all collected during daylight, the Ped ISI and Bike ISI may not accurately identify sites that would be particularly hazardous at night.

COUNTERMEASURES

Once pedestrian crossings and bicycle approaches to intersections have been prioritized for safety improvements, the practitioner will have many options of analysis and treatment. The authors recommend PEDSAFE and BIKESAFE as excellent tools to assist in the selection of appropriate countermeasures. PEDSAFE is available from FHWA (Harkey and Zegeer, 2004). The online version can be accessed at www.walkinginfo.org/pedsafe. BIKESAFE is in its final stages of review and is due to be released in 2006 (Hunter, et al., 2005). The online version can be accessed at www.bicyclinginfo.org/bikesafe.

PEDSAFE and BIKESAFE are designed to recommend treatments for specific safety problems. In order to make full use of the information provided in these tools, the practitioner will need to gather knowledge of the most common safety problems at each site to be addressed. This step can be done through examining the types of crashes that occur at the site or through observational analysis of pedestrians, bicyclists, and motorists at the site.

PEDSAFE

The PEDSAFE Guide provides details on 49 different types of safety treatments that can be used to improve pedestrian safety and/or mobility. This Guide also includes information on the specific types of countermeasures that may be appropriate for addressing such objectives as:

- Reduce speed of motor vehicles.
- Improve sight distance and visibility for motorists and pedestrians.
- Reduce volume of motor vehicles.
- Reduce exposure for pedestrians.
- Improve pedestrian access and mobility.
- Encourage walking by improving aesthetics.
- Improve compliance with traffic laws.
- Eliminate behaviors that lead to crashes.

A listing of pedestrian-related treatments for each of these eight performance objectives is given in Figure 13 and Figure 14 by "categories" of treatments, including pedestrian facility design, roadway design, intersection design, traffic calming, traffic management, and signals and signs. For example, to reduce the speed of motor vehicles, some of the possible roadway design treatments include adding bike lane or shoulder, road narrowing, reducing the number of lanes, driveway improvements, curb radius reduction, or adding a right-turn slip lane.

The PEDSAFE Guide also gives a description of 12 specific pedestrian crash types (e.g., dart/dash, walking along roadway, turning vehicle, multiple-threat), with corresponding countermeasure options for each crash type. The Guide also contains write-ups for 71 case studies of pedestrian improvements that have been implemented in the United States. Also, the expert system software is provided to allow a user to input the type of pedestrian safety problem, along with the location or roadway section characteristics, such as intersection or midblock, type of control devices (e.g., traffic signal, stop sign, no control), number of lanes, and traffic volume. The software then will generate a "short list" of countermeasure options based on the type of pedestrian safety problem and site characteristics.

BIKESAFE

The BIKESAFE Guide also gives similar types of information on countermeasures for bike-related crashes. For example, countermeasure options are given for the following objectives:

- Provide safe on-street facilities/space for bicyclists.
- Provide off-road paths or trails for bicyclists.
- Provide and maintain quality surfaces for bicyclists.
- Provide safe intersections for bicyclists.
- Improve motorist behavior/compliance with traffic laws.

- Improve bicyclist behavior/compliance with traffic laws.
- Encourage and promote bicycling.

There are nine categories of bicycle treatments given in Figure 15 and Figure 16, including those involving shared-roadway treatments; on-road bike facilities; intersection treatments; maintenance measures; traffic calming; trails/mixed-use paths; markings, signs, and signals; education and enforcement; and support facilities and programs. For example, potential measures to improve bike safety at intersections include curb radii revisions, roundabouts, intersection markings, sight-distance improvements, turning restrictions, and the redesign of the bike/motor vehicle merge area. BIKESAFE also provides a matrix of potential bike safety treatments that correspond to 13 different types of bicycle crashes.

The BIKESAFE Guide also provides details of more than 50 case studies from the United States and abroad related to past safety improvements. As with PEDSAFE, the BIKESAFE Guide includes a CD-ROM that allows an engineer, planner, or other safety professional to enter the basic crash or information or performance objectives for a location or section, along with site characteristics. The expert system software will then give a short list of candidate countermeasures that are appropriate for those conditions.

	A. Pedestrian Facility Design	B.Roadway Design	C.Intersection Design
OBJECTIVE			
1. Reduce Speed of Motor Vehicles *To be used in conjunction with other treatments	• Street Furniture*	• Add Bike Lane/Shoulder • Road Narrowing • Reduce Number of Lanes • Driveway Improvements • Curb Radius Reduction • Right-Turn Slip Lane	• Modern Roundabouts
2. Improve Sight Distance and Visibility for Motor Vehicles and Pedestrians	• Crosswalk Enhancements • Roadway Lighting • Move Poles/Newspaper Boxes at Street Corners	• Add Bike Lane/Shoulder	
3. Reduce Volume of Motor Vehicles		• Reduce Number of Lanes	
4. Reduce Exposure for Pedestrians	• Overpasses/Underpasses	• Road Narrowing • Reduce Number of Lanes • Raised Median • Pedestrian Crossing Island	
5. Improve Pedestrian Access and Mobility	• Sidewalk/Walkway • Curb Ramps • Crosswalk Enhancements • Transit Stop Treatments • Overpasses/Underpasses	• Raised Median	
6. Encourage Walking by Improving Aesthetics	• Street Furniture • Roadway Lighting • Landscaping Options	• Raised Median	
7. Improve Compliance With Traffic Laws			• Red-Light Cameras
8. Eliminate Behaviors That Lead to Crashes			• Red-Light Cameras

Figure 13. Matrix of pedestrian safety countermeasures associated with various objectives.

D. Traffic Calming	E. Traffic Management	F. Signals and Signs	G.Other Measures
• Curb Extension • Choker • Chicane • Mini-Circle • Speed Humps • Speed Table • Raised Pedestrian Crossing • Raised Intersection • Driveway Link/Serpentine • Woonerf • Landscaping Options* • Paving Treatments*		• Signal Enhancement (e.g., Adjust Signal Timing for Motor Vehicles) • Sign Improvement*	• Speed-Monitoring Trailer • School Zone Improvement
• Curb Extension • Speed Table • Raised Pedestrian Crossing • Raised Intersection • Paving Treatments		• Sign Improvement (e.g., Warning Sign) • Advanced Stop Lines	
• Woonerf	• Diverters • Full Street Closure • Partial Street Closure • Pedestrian Street		
• Curb Extension • Choker • Pedestrian Crossing Island		• Pedestrian Signal Timing • Accessible Pedestrian Signal	
• Choker • Pedestrian Crossing Island		• Traffic Signal • Signal Enhancement • Accessible Pedestrian Signal • Pedestrian Signal Timing	
• Gateway • Landscaping • Paving Treatments			• Identify Neighborhood
• Traffic Calming: Choker, Chicane, Mini-Circle, Speed Hump, Speed Table			• Speed-Monitoring Trailer • Pedestrian/Driver Education • Police Enforcement
• Traffic Calming: Choker, Chicane, Mini-Circle, Speed Hump, Speed Table		• Pedestrian Signal Timing	• Pedestrian/Driver Education • Police Enforcement

Figure 14. Matrix of pedestrian safety countermeasures associated with various objectives (continued).

Objectives	Shared Roadway	On-Road Bike Facilities	Intersection Treatments	Maintenance
1) Provide safe on-street facilities/ space for bicyclists.	· Roadway Surface Improvements · Bridge Access · Tunnel Access · Roadway Lighting · Parking Treatments · Median/Crossing Island · Driveway Improvements · Access Management · Reduce Lane Number · Reduce Lane Width	· Bike Lanes · Wide Curb Lanes · Paved Shoulders · Combination Lanes · Contraflow Bike Lanes		· Repetitive/Short Term Maintenance · Major Maintenance · Hazard Identification Program
2) Provide off-road paths or trails for bicyclists.				· Repetitive/Short Term Maintenance · Major Maintenance · Hazard Identification Program
3) Provide and maintain quality surfaces for bicyclists.	· Roadway Surface Improvements			· Repetitive/Short Term Maintenance · Major Maintenance · Hazard Identification Program
4) Provide safe intersections for bicyclists.	· Roadway Lighting		· Curb Radii Revisions · Roundabouts · Intersection Markings · Sight Distance Improvements · Turning Restrictions · Merge Area Redesign	
5) Improve motorist behavior/compliance with traffic laws.	· Roadway Lighting · Reduce Lane Width		· Curb Radii Revisions · Roundabouts · Intersection Markings · Turning Restrictions · Merge Area Redesign	
6) Improve bicyclist behavior/compliance with traffic laws.	· Parking Treatments	· Bike Lanes		
7) Encourage and promote bicycling.	· Roadway Surface Improvements · Bridge Access · Tunnel Access · Median/Crossing Island	· Bike Lanes		

Figure 15. Matrix of bicyclist safety countermeasures associated with various objectives.

Traffic Calming	Trails/Mixed Use Paths	Markings, Signs, Signals	Education and Enforcement	Support Facilities and Progran
	· Separate Mixed Use Path · Trail Intersection Treatments · Intersection Warning Treatments · Share the Trail Treatments	· Sign Improvements · Pavement Marking Improvements		· Wayfinding · Aesthetics/Landscaping
· Mini Traffic Circles · Speed Tables/Humps/Cushions · Raised Intersection	· Trail Intersection Treatments · Intersection Warning Treatments	· Install Signal/Optimize Timing · Bike-activated Signal · Sign Improvements · Pavement Marking Improvements · School Zone Improvements	· Practitioner Education	
· Mini Traffic Circles	· Trail Intersection Treatments · Intersection Warning Treatments · Share the Trail Treatments	· Install Signal/Optimize Timing · Bike-activated Signal	· Law Enforcement · Bicyclist Education	· Wayfinding · Aesthetics/Landscaping

Figure 16. Matrix of bicyclist safety countermeasures associated with various objectives (continued).

RECOMMENDATIONS FOR FUTURE RESEARCH

Expansion of Scope

As discussed, the safety ratings did not extend to the full range of possible ratings (i.e., very few 5's and 6's). This was due to the fact that the study sites were selected to include those locations with high volumes of pedestrian and bicyclist activity. These high volumes were necessary for the collection of behavioral data. However, obtaining expert safety ratings is not dependent on having high volumes of pedestrian or bicyclist activity. Future research that uses expert safety ratings may consider including sites that would be considered more hazardous (e.g., heavier and faster traffic, fewer pedestrian or bicycle facilities, etc.). This type of study design could yield a model that would give prioritization of a wider range of intersection types.

Field Validation

The Ped ISI and Bike ISI would benefit from a large-scale field validation effort in one or more cities. The intended field validation would consist of selecting a group of intersections, independently rating them with the safety index tool and ped/bike safety experts, and comparing the two ratings. The effort could also compare the ratings with safety data, such as crashes and conflicts. Probable outcomes of this procedure would be a validation of the type and magnitude of the variables in the safety index models, as well as possible modifications to the models based on feedback from the safety experts.

Crash-Based Validation

The models developed in this study should be considered for future validation with more extensive pedestrian and bicyclist crash-based models. Specifically, as future studies are able to better quantify pedestrian and bicyclist crash effects of various intersection features, such information should be used to modify the safety index models accordingly. The inclusion of a greater number of sites may lead to a more sensitive model that would reflect the effects of smaller factors, such as median type and width.

APPENDIX A: DATA COLLECTION INSTRUCTIONS AND FORMS

Instructions for Videotaping Pedestrian Sites

General

I will give you a list of intersections and indicate which crosswalk is of interest (e.g., Market Street at 5th Street, N leg). Assume that Market Street is an east-west street. Then the east and west legs of the intersection are Market Street, and the north and south legs are 5th Street. The crosswalk of interest crosses the north leg of Market Street (see Figure 17). There are separate instructions for signalized and unsignalized intersections.

Panning the Intersection

When you first arrive at an intersection, use the camera on your shoulder to pan around the area. First videotape in front of you, then to the left for a cross-street view, then behind you, and then to the right for the other cross-street view. This gives data coders a sense of the total "look" at this location. Describe in words what you are videotaping (i.e., the street names, what is on each corner, the direction you are looking at, etc.).

Signalized Intersections

You will be videotaping at four places for each intersection: (1) crosswalk of interest, (2) opposite direction, (3) upstream from crosswalk, and (4) downstream from crosswalk. These are explained below.

<u>**Crosswalk of Interest**</u>

1. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, including the push button locations, the pedestrian signal heads, the traffic signal head for parallel traffic, and vehicles in the rightmost travel lane. The preferred camera position is shown as Position #1 in Figure 18. Note that the camera is facing the same direction as traffic in the lane closest to you. If this position is not feasible, then Position #2 shown in Figure 19 can be used. Here the camera is facing the opposite direction as traffic in the lane closest to you. The camera should be approximately 7 to 8 feet above the ground. The camera should be set up about 75 to 100 feet from the intersection. Zoom in to get the desired view.

2. Videotape for 1 hour-40 minutes at each site. Be careful to avoid fatigue (take breaks if necessary). Use S-VHS mode. An "S" will appear in the upper left-hand corner of the view screen when this is the case. There is a switch on top of the camera that should be in the "on-auto" position to make sure the camera is in the S-VHS mode.

3. Be sure to describe in words what you are videotaping ("I'm at Market and 34th streets, and I'm looking south across Market, filming the west crosswalk.").

4. The camera may not be able to see whether a pedestrian pushed a button to activate the WALK signal. Sometimes the traffic signal head or the ped head is not visible. Please

narrate as you are filming ("ped pushed button," "WALK," "flashing," "DON'T WALK," "green light," "yellow," "red"). Set microphone on the "wide" setting. Speak loudly so you can be heard over the noise of traffic. Feel free to comment on anything noteworthy.

Opposite Direction

5. If you videotaped from Position #1, now move the ladder and camera to Position #2. Set up about 75 to 100 feet back from the intersection. Zoom in to get a closeup view and then zoom out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping ("This is a view along 34th Street, looking north across Market Street"). When you are done, go to Step 7.

6. If you videotaped from Position #2, now move the ladder and camera to Position #1. Set up about 75 to 100 feet back from the intersection. Zoom in to get a closeup view and then zoom out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping ("This is a view along 34th Street, looking north across Market Street.").

Upstream From Crosswalk

7. Move the ladder and camera to Position #3 as shown in Figure 20. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, and the vehicles in the travel lanes. Set up about 150 to 200 feet back from the intersection. Zoom in to get a closeup view and then zoom back out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping ("This is a view along Market Street, looking east across 34th Street.").

Downstream From Crosswalk

8. Move the ladder and camera to Position #4 as shown in Figure 21. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, and the vehicles in the travel lanes. Set up about 150 to 200 feet back from the intersection. Zoom in to get a closeup view and then zoom back out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping ("This is a view along Market Street, looking west across 34th Street.").

Unsignalized Intersections

You will be videotaping at four places for each intersection: (1) crosswalk of interest, (2) opposite direction, (3) across crosswalk—same direction, and (4) across crosswalk—opposite direction. These are explained below.

Crosswalk of Interest

1. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, and the vehicles in the travel lanes. Use Position #3 as shown in Figure 20. The camera should be approximately 7 to 8 feet above the ground. The

camera should be set up about 150 to 200 feet from the intersection. Zoom in to get the desired view.

2. Videotape for 1 hour-40 minutes at each site. Be careful to avoid fatigue (take breaks if necessary). Use S-VHS mode. An “S” will appear in the upper left-hand corner of the view screen when this is the case. There is a switch on top of the camera that should be in the “on-auto” position to make sure the camera is in the S-VHS mode.

3. Be sure to describe in words what you are videotaping (“I’m at Filbert and 10th Streets, and I’m looking east along Filbert, filming the west crosswalk.”). Feel free to narrate anything noteworthy that you see.

<u>Opposite Crosswalk</u>

4. Move the ladder and camera to Position #4 as shown in Figure 21. Set up about 150 to 200 feet back from the intersection. Zoom in to get a closeup view and then zoom out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping (“This is a view along Filbert Street, looking west.”).

<u>Across Crosswalk—Same Direction</u>

5. Move the ladder and camera to Position #1 as shown in Figure 18. Note that the camera is facing the same direction as traffic in the lane closest to you. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, and the vehicles in the rightmost travel lane. Set up about 75 to 100 feet back from the intersection. Zoom in to get a closeup view and then zoom back out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping (“This is a view along 10th Street, looking south across Filbert.”).

<u>Across Crosswalk—Opposite Direction</u>

6. Move the ladder and camera to Position #2 as shown in Figure 19. Note that the camera is facing the opposite direction as traffic in the lane closest to you. The camera needs to be set up so that it can see the entire crosswalk, the queuing areas on either side of the crosswalk, and the vehicles in the rightmost travel lane. Set up about 75 to 100 feet back from the intersection. Zoom in to get a closeup view and then zoom back out again. About 4 minutes of footage should be sufficient. Describe in words what you are videotaping (“This is a view along 10th Street, looking north across Filbert.”).

<u>Other Tips</u>

1. Please fill out the data collection form at each intersection.

2. You will use a stepladder to be able to see over traffic. Always wear your vest.

3. Videotape during daylight hours under dry conditions (not raining). Do not videotape on days where traffic is disrupted because of a crash, a parade, or anything else out of the

ordinary—we are trying to videotape normal traffic flow for the chosen intersection for the time of day selected.

4. Take into consideration the sun angle. Choose filming times and camera positions to minimize glare.

5. A fresh battery pack should be good for about 1.5 to 2 hours, so make sure that you have spares. You will need to keep two or three battery packs ready for each time you go out. When filming, keep track of battery "freshness." You will see four marks in the viewfinder when the battery is fully charged. These decrease as the battery becomes weaker. When only two marks are showing, the battery will discharge fairly quickly.

6. Proceed to all intersections in the same manner. Use a separate tape for each location and label city, site, date, and time of filming (e.g., PHILADELPHIA—MARKET & 34th, W LEG—7/07/02—3:30-5:30 p.m.). Use FedEx® labels to send the videotapes to me.

7. While you are videotaping, passersby may ask what you are doing. You should always be courteous in your response and simply state that you are doing a traffic study. This answer will usually suffice.

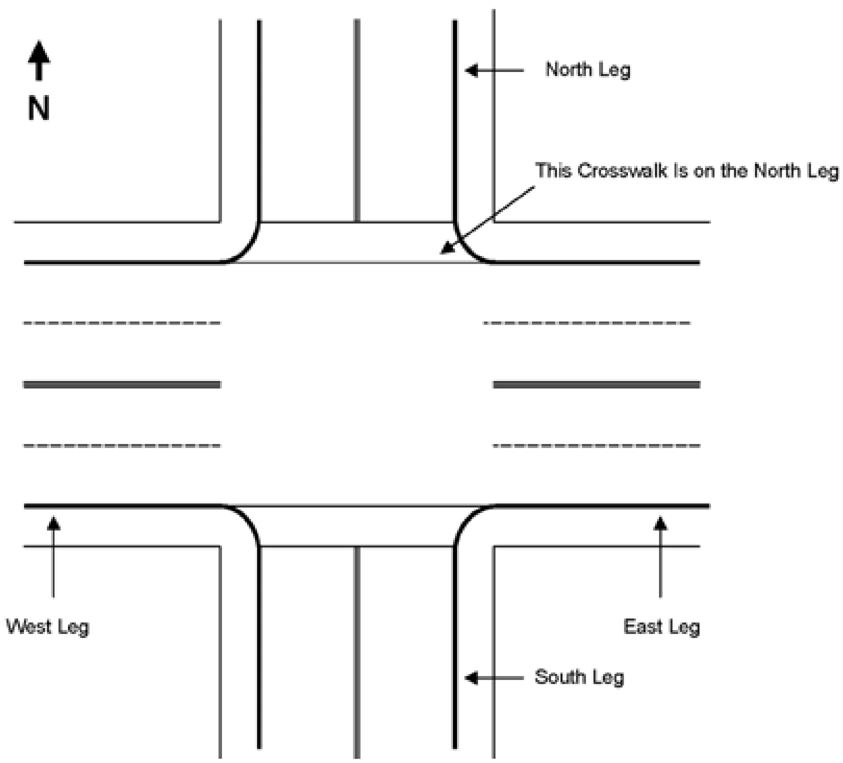


Figure 17. Intersection Leg Labels

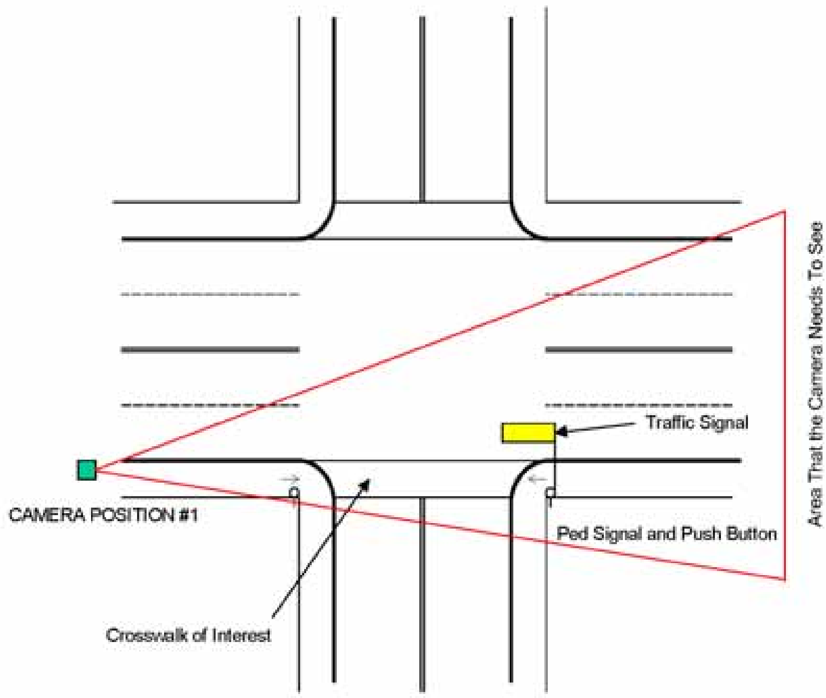


Figure 18. Camera Position #1

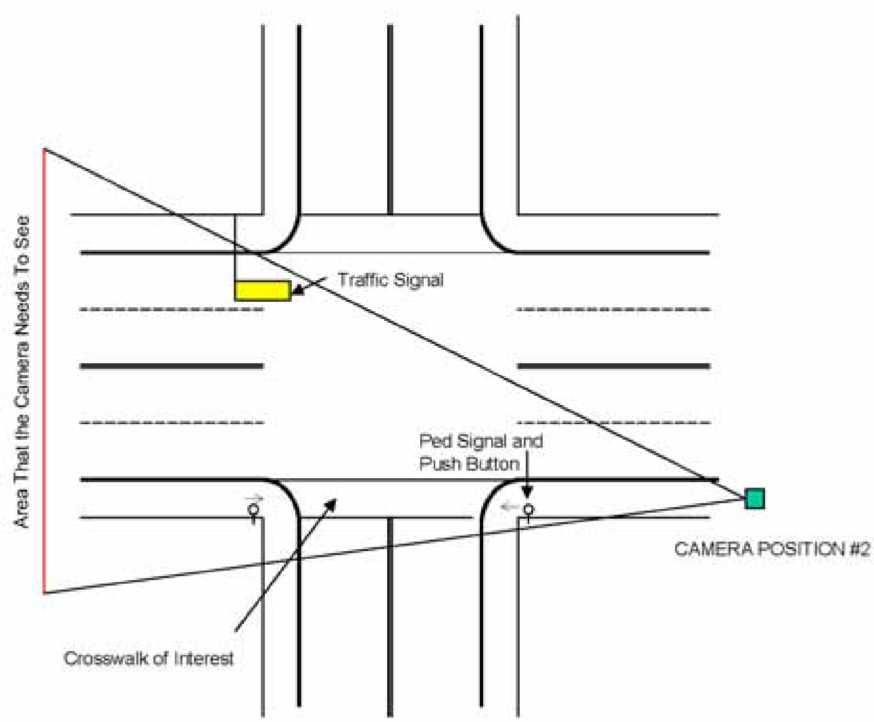


Figure 19. Camera Position #2

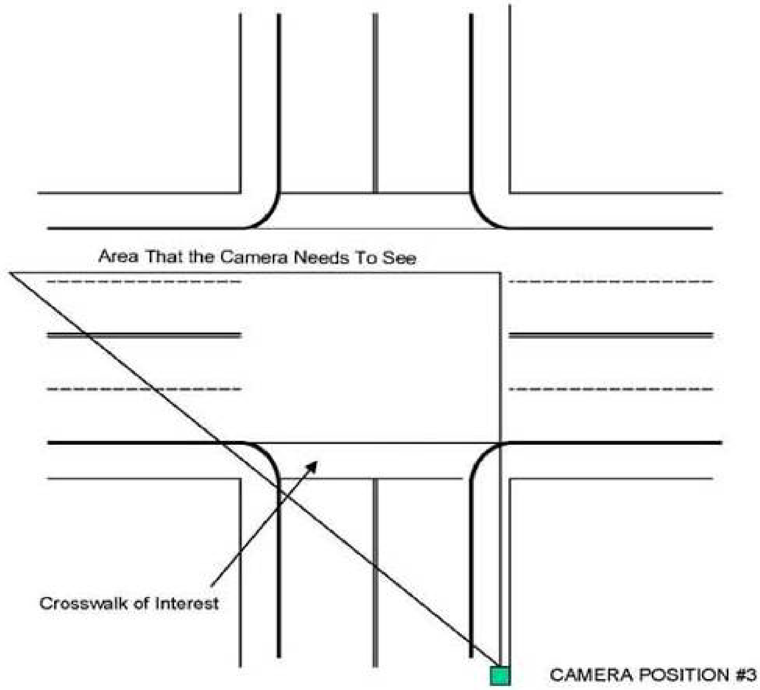
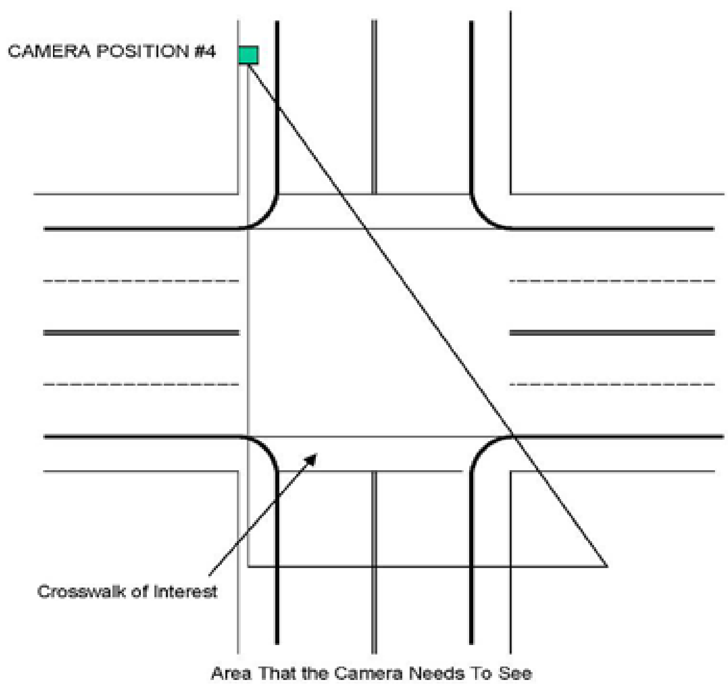


Figure 20. Camera Position #3Figure 21. Camera Position #4



Data Collection Form for Pedestrian Sites

LOCATION

City: ________________________________

Main Street: ________________________________

Side Street: ________________________________

Note: Indicate if streets change names.

DATES AND TIMES OF DATA COLLECTION (List all that apply)

____

____

DATA COLLECTOR(S)

_______________________ _______________________

VEHICLE TRAFFIC CONTROL

☐ Signals
☐ STOP sign, all legs
☐ STOP sign, side street only
☐ Flasher
☐ Other ________________________________

INTERSECTION TYPE

☐ Four-way ☐ T-intersection

ONE-WAY OR TWO-WAY

Main Street, ___ leg:	☐ One-way	☐ Two-way
Main Street, ___ leg:	☐ One-way	☐ Two-way
Side Street, ___ leg:	☐ One-way	☐ Two-way
Side Street, ___ leg:	☐ One-way	☐ Two-way

NUMBER OF LANES

Main Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Main Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Side Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Side Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present

Note: Thru lanes include combined thru/RT and thru/LT lanes.

CROSSING WIDTH

Main Street, ___ leg: _____ ft
Main Street, ___ leg: _____ ft
Side Street, ___ leg: _____ ft
Side Street, ___ leg: _____ ft

Note: If there is a marked crosswalk, measure the crossing width from curb-to-curb along the middle of the crosswalk.

MARKED CROSSWALKS

Main Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Main Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Side Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Side Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None

CROSSING ISLANDS

Main Street, __ leg: ☐ Yes, _____ ft wide ☐ No
Main Street, __ leg: ☐ Yes, _____ ft wide ☐ No
Side Street, __ leg: ☐ Yes, _____ ft wide ☐ No
Side Street, __ leg: ☐ Yes, _____ ft wide ☐ No

PEDESTRIAN SIGNALS

Main Street, ___ leg:

☐ WALK/DON'T WALK	☐ Hand/walking man	☐ None
Is it push button activated?	☐ Yes	☐ No

Main Street, ___ leg:

☐ WALK/DON'T WALK	☐ Hand/walking man	☐ None
Is it push button activated?	☐ Yes	☐ No

Side Street, ___ leg:

☐ WALK/DON'T WALK	☐ Hand/walking man	☐ None
Is it push button activated?	☐ Yes	☐ No

Side Street, ___ leg:

☐ WALK/DON'T WALK	☐ Hand/walking man	☐ None
Is it push button activated?	☐ Yes	☐ No

PEDESTRIAN-RELATED SIGNS (for motorists)

Main Street, ___ leg:
☐ Advance Pedestrian Crossing
☐ Pedestrian Crossing
  ☐ Overhead
☐ NO TURN ON RED
☐ Overhead flasher
☐ Other ____________________
☐ Other ____________________

Main Street, ___ leg:
☐ Advance Pedestrian Crossing
☐ Pedestrian Crossing
  ☐ Overhead
☐ NO TURN ON RED
☐ Overhead flasher
☐ Other ____________________
☐ Other ____________________

Side Street, ___ leg:
☐ Advance Pedestrian Crossing
☐ Pedestrian Crossing
  ☐ Overhead
☐ NO TURN ON RED
☐ Overhead flasher
☐ Other ____________________
☐ Other ____________________

Side Street, ___ leg:
☐ Advance Pedestrian Crossing
☐ Pedestrian Crossing
  ☐ Overhead
☐ NO TURN ON RED
☐ Overhead flasher
☐ Other ____________________
☐ Other ____________________

RIGHT-TURN CURB RADII

Main Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Main Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Side Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Side Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable

ON-STREET PARKING

Main Street, ___ leg: ☐ Allowed, cars present ☐ Allowed, but no cars present ☐ Not allowed

Main Street, ___ leg: ☐ Allowed, cars present ☐ Allowed, but no cars present ☐ Not allowed

Side Street, ___ leg: ☐ Allowed, cars present ☐ Allowed, but no cars present ☐ Not allowed

Side Street, ___ leg: ☐ Allowed, cars present ☐ Allowed, but no cars present ☐ Not allowed

STREET LIGHTING

Main Street, ___ leg: ☐ Yes ☐ No
Main Street, ___ leg: ☐ Yes ☐ No
Side Street, ___ leg: ☐ Yes ☐ No
Side Street, ___ leg: ☐ Yes ☐ No

TYPE OF DEVELOPMENT AT INTERSECTION

(For example, shops, restaurant, gas station, school, church, houses, apartments, offices.)

Northeast Corner ____________________
Northwest Corner ____________________
Southeast Corner ____________________
Southwest Corner ____________________

INTERSECTION SKETCH

Instructions for Videotaping Bicycle Sites

General

Refer to any maps, site lists, and diagrams for detailed location information. You will be videotaping at three places for each intersection: (1) oncoming bicycles and motor vehicles, (2) view of cross-street traffic, and (3) view from rear of traffic. These will be explained individually. Also see attached diagrams. You will use a stepladder to be able to see over traffic in all three cases. Always wear your vest. Do not videotape on days where traffic is disrupted because of a crash or something out of the ordinary—we are trying to videotape normal traffic flow for the chosen intersection for the time of day selected.

When you first arrive at the location, use camera on your shoulder to pan around the area. First videotape in the direction for **oncoming** bikes, then to the left for a side street view, then back to the leg with oncoming bikes, then to the right for the other side street direction, and then behind. This gives data coders a sense of the total "look" at this location. Describe in words what you are videotaping (i.e., site, date, time of day, etc.).

Oncoming Bicycles and Motor Vehicles

1. Set up stepladder so you can videotape bicyclist's path approaching and riding through the intersection. We are interested in knowing if they stayed on the road or moved to a sidewalk or other location, so try to follow their path.

2. We will try to provide a recommendation of when is the best time to videotape for maximum number of bicyclists, but it may require some scouting on your part.

3. Videotape bicyclists approaching the camera location at the intersection (i.e., coming toward the camera). Try to set up far enough back from the intersection (about 150 to 200 feet) so you can see bicyclists come through the intersection proper and whether they go straight, turn right, or turn left. Line-of-sight limitations may force a different setup position. We need to be able to see their intersection maneuver (e.g., came straight through and then switched to a sidewalk, turned right and stayed in the street, etc.). Then follow the cyclists for a short distance as they move away from the intersection.

4. Videotape oncoming traffic for 1 hour-45 minutes at each site. Be careful to avoid fatigue (take a break every 15 to 20 minutes if necessary). Make sure date and time switch on camera is turned on. Use S-VHS mode. An "S" will appear in the upper left-hand corner of the view screen when this is the case. There is a switch on top of the camera that should be in the "on-auto" position to make sure the camera is in the S-VHS mode. Try to zoom in on cyclist to have clear view of conflicts with motor vehicles unless multiple bikes in view. If multiple bikes, try for "best of both worlds." Videotape as many of the cyclists coming toward the camera as possible. Use the special form to keep a tally of cyclists by location (in street, on sidewalk). Fill in count on log when complete.

5. We will rarely be able to see the traffic signal indication at an intersection, so person filming needs to indicate if cyclist "runs" the signal. Likewise for stop sign, flashing red

signal, or other control. Set microphone on the “wide” setting. Speak loudly so you can be heard over the noise of traffic. Feel free to comment on anything noteworthy.

6. Be careful of sun angle. Choose time and location at intersection to minimize problem.

7. Fresh battery pack should be good for about 1.5 to 2 hours, so make sure you have spares. You will need to keep two or three battery packs ready for each time you go out. See separate instructions related to camera. When filming, keep track of battery “freshness.” There are four marks present when the battery is fully charged. These decrease as battery becomes weaker. When only two marks are showing, the battery will become discharged fairly quickly.

8. Proceed to all sites in the same manner. Use separate tapes for each location and label city, site, date, and time of filming (e.g., PHILADELPHIA—WALNUT & 34th—4/07/02—3:30-5:30 p.m.). Use FedEx labels to send videotapes to me. Fill in logs as filming and exposure data are collected and fax periodically, or send to me in the FedEx packages.

View of Cross-Street Traffic

1. Move ladder and camera to the cross street position shown in the diagram. If this location is on a steep downgrade, or there are other physical characteristics that make it difficult to get a good view, then move to the opposite side of the intersection. Set up about 150 to 200 feet back from intersection. Zoom in to give a closeup view and then zoom back out again. It is preferable to show normal movement of traffic into the intersection. About 3 to 4 minutes of footage should be sufficient. Describe in words what you are videotaping (“This is a view of the traffic approaching on _____ Street, the cross street.”)

View From Rear of Traffic

1. Move ladder and camera to the rear-of-traffic position. Again set up about 150 to 200 feet back from intersection. Zoom in to give a closeup view. Try for a view with little traffic as you zoom in so that lane lines and other markings might be seen. Then zoom back out again. Videotape from this position until the rest of the videotape is completed (should be about 10 minutes or so).

Establish time to do weekly phone call.

Data Collection Form for Bicycle Sites

LOCATION

City: ________________________________
Main Street: ________________________________
Side Street: ________________________________

Note: Indicate if streets change names.

____
____

DATES AND TIMES OF DATA COLLECTION (List all that apply)

____
____

DATA COLLECTOR(S)

______________________ ______________________

VEHICLE TRAFFIC CONTROL

MAIN STREET

☐ Signals
☐ STOP sign, all legs
☐ STOP sign, side street only
☐ Flasher
☐ Other ______________________
☐ Flasher

SIDE STREET

☐ Signals
☐ STOP sign, all legs
☐ STOP sign, side street only
☐ Flasher
☐ Other ______________________
☐ Flasher

INTERSECTION TYPE

☐ Four-way ☐ T-intersection ☐ Other

ONE-WAY OR TWO-WAY

Main Street, ___ leg: ☐ One-way ☐ Two-way
Main Street, ___ leg: ☐ One-way ☐ Two-way
Side Street, ___ leg: ☐ One-way ☐ Two-way
Side Street, ___ leg: ☐ One-way ☐ Two-way

Note: For this and other items, where appropriate, label legs as N, S, E, or W. North is the leg on the North side of the street.

NUMBER OF LANES

Label legs as N, S, E, or W and indicate number of thru, right-, and left-turn lanes, and whether there is a two-way center left-turn lane present.

Main Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Main Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Side Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present
Side Street, ___ leg: _____ Thru lanes _____ RT only lanes _____ LT only lanes
☐ Two-way center turn lane present

Note: Thru lanes include combined thru/RT and thru/LT lanes.

CROSSING WIDTH (expressed in terms of number of lanes crossed)

Main Street, ___ leg: _____ number of side street lanes crossed

MARKED CROSSWALKS (See attached diagram)

Main Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Main Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Side Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None
Side Street, ___ leg: ☐ Parallel lines ☐ Continental ☐ Ladder
☐ Zebra ☐ Other __________________ ☐ None

CROSSING ISLANDS

Along the main leg on which the bicycle travels:

Is there a right-turn lane crossing island?	☐ yes	☐ no	☐ Not applicable
Is it big enough to allow refuge for a bicyclist?	☐ yes	☐ no	☐ Not applicable
Is there a median island?	☐ yes	☐ no	☐ Not applicable
Is it big enough to allow refuge for a bicyclist?	☐ yes	☐ no	☐ Not applicable

RIGHT-TURN CURB RADII

Main Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Main Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Side Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable
Side Street, ___ leg:	☐ Large/wide	☐ Small/tight	☐ Not applicable

ON-STREET PARKING

Is on-street parking allowed within 4 to 5 car lengths of intersection?

Main Street, ___ leg:	☐ Allowed, cars present	☐ Allowed, but no cars present
	☐ Not allowed, cars present	☐ Not allowed, cars not present
Main Street, ___ leg:	☐ Allowed, cars present	☐ Allowed, but no cars present
	☐ Not allowed, cars present	☐ Not allowed, cars not present
Side Street, ___ leg:	☐ Allowed, cars present	☐ Allowed, but no cars present
	☐ Not allowed, cars present	☐ Not allowed, cars not present
Side Street, ___ leg:	☐ Allowed, cars present	☐ Allowed, but no cars present
	☐ Not allowed, cars present	☐ Not allowed, cars not present

STREET LIGHTING

Main Street, ___ leg:	☐ Present	☐ Not present
Main Street, ___ leg:	☐ Present	☐ Not present
Side Street, ___ leg:	☐ Present	☐ Not present
Side Street, ___ leg:	☐ Present	☐ Not present

TYPE OF DEVELOPMENT AT INTERSECTION

(For example, shops, restaurant, gas station, school, church, houses, apartments, offices, etc.)

Northeast Corner ______________________________

Northwest Corner ______________________________

Southeast Corner ______________________________

Southwest Corner ______________________________

RIGHT TURN ON RED (Main Leg)

☐ Allowed ☐ Not allowed ☐ Not applicable

SIGHT DISTANCE (Main Leg)

Describe bicyclist sight distance approaching the cross street intersection:

☐ Good ☐ Fair ☐ Poor

NUMBER OF DRIVEWAYS (Main Street)

Approach leg: # driveways within 300 ft of intersection, both sides of street ______
Departing leg: # driveways within 300 ft of intersection, both sides of street ______

INTERSECTION SKETCH

Draw a sketch of the intersection that shows the lanes on main and side streets; other intersection features such as crossing islands, driveways, and parking; and location of camera for the 1 hour-45 minutes of videotaping. Show a North arrow and label each leg as N, S, E, W.

APPENDIX B. CONFLICTS INVOLVING BICYCLISTS

The following table describes the 17 conflicts observed during the bicycle study.

No.	Site	Conflicting Party	Conflict Description
1	101	Vehicle	Bicyclist crosses in crosswalk and brakes for right-turning vehicle. Vehicle stops.
2	106	Vehicle	Person in parked vehicle opens door just as bike comes by, causing bicyclist to swerve and brake suddenly, almost losing control of bicycle.
3	118	Vehicle	Occupant of parked vehicle opens door just as bike comes by, causing bicyclist to swerve and brake suddenly.
4	122	Pedestrian	Pedestrian crosses street midblock between heavy traffic, does not see oncoming bike that has to stop suddenly, almost losing control.
5	124	Vehicle	Bicyclist on crosswalk swerves to avoid right-turning vehicle. Vehicle brakes hard.
6	124	Vehicle	Bicyclist swerves to avoid stopped vehicle; another vehicle from behind attempts to pass but has to brake because bicyclist is passing in front of them.
7	126	Vehicle	Bicyclist crosses street in front of oncoming vehicle, forcing the motorist to stop. Bicyclist has trouble pedaling and lingers in middle of street.
8	140	Vehicle	Bicyclist crosses intersection on red signal causing oncoming motorist to brake. Bicyclist swerves to avoid collision.
9	143	Vehicle	Bicyclist swerves left to avoid stopped vehicle ahead. Bicyclist swerves in front of vehicle in adjacent lane, causing motorist to brake suddenly.
10	144	Pedestrian	Bicyclist enters intersection on red signal and almost hits pedestrian crossing street.
11	209	Vehicle	Motorist turns right in front of bicyclist in adjacent bike lane, causing bicyclist to brake hard and swerve suddenly.
12	209	Vehicle	Bicyclist does not stop for red signal but instead swerves back and forth in bike lane and adjacent lanes, not watching for vehicles in adjacent lanes. Motorist in right-turn lane has to brake suddenly to avoid swerving bike.
13	315	Vehicle	Motorist in through lane cuts to right to get into right-turn lane, in front of adjacent bicyclist, causing bicyclist to brake hard and swerve.
14	402	Vehicle	Bicyclist crosses in front of oncoming vehicle, causing motorist to brake suddenly. Driver blows horn, bicyclist increases speed and proceeds across.
15	412	Vehicle	Bicyclist in bike lane makes left turn in near crosswalk, goes halfway across, then stops for traffic making left turn from cross street. Bicyclist eventually does U-turn.
16	424	Vehicle	Bicyclist enters intersection as signal changes from yellow to red. Vehicle on side street starts through on green but has to stop for bicyclist. Bicyclist also brakes.
17	425	Vehicle	Motorist makes left turn in front of oncoming bicyclist in bike lane at unsignalized intersection. Bicyclist has to brake suddenly and stop. Motorist also brakes, then proceeds slowly.

APPENDIX C. WEB SITES FOR SAFETY RATINGS SURVEY

Participants in the safety rating surveys were instructed to visit a particular Web address to begin the survey. The following figures show screenshots of the different sections of the survey Web sites. Figure 22 and Figure 23 shows screens from both the pedestrian and the bicyclist surveys (pedestrian image on left, bicyclist image on right). Even though similar, there were some differences in the type of information given and the information requested of the evaluator.

The first page on the survey Web site was the introduction page (Figure 22 and Figure 23). This page allowed new participants to create a profile and begin the survey or returning users to log back in and pick up where they left off.

Figure 22. Pedestrian survey introduction page.

Figure 23. Bicycle survey introduction page.

After creating a login profile, users were prompted for certain information regarding their demographics and experience (Figure 24 and Figure 25). These data were later used to ensure that survey ratings had been given by a diverse group of evaluators.

Figure 24. Preliminary pedestrian user questions.

Figure 25. Preliminary bicyclist user questions.

Survey instructions were provided to the user (Figure 26 and Figure 27). These instructions demonstrated the steps that would need to be followed to give a rating.

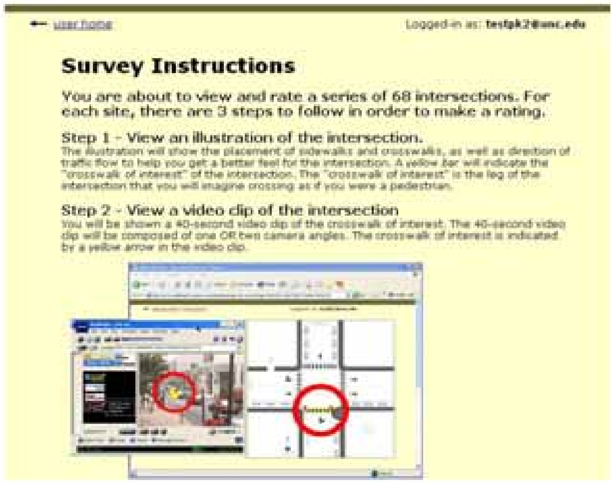


Figure 26. Pedestrian survey instructions.

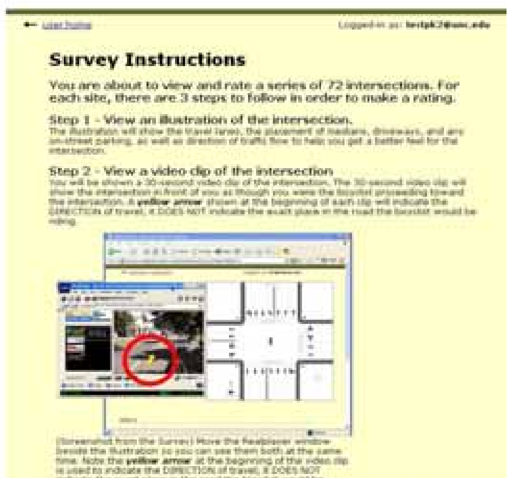


Figure 27. Bicycle survey instructions.

Before users began the actual survey, they were first shown a page with two sample intersections (Figure 28 and Figure 29). They were given the opportunity to familiarize themselves with the survey format by viewing the illustration and video clip. The two example sites also gave them an idea of the range of conditions they would see during the survey.

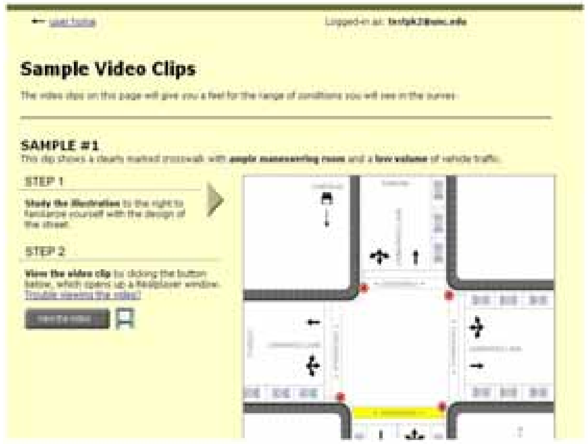


Figure 28. Sample pedestrian video clips page.

Figure 29. Sample bicycle video clips page.

A rating page for a particular site consisted of top and bottom sections. The top section (Figure 30 and Figure 31) gave the necessary information through the illustration and video clip. The bottom section (Figure 32 and Figure 33) presented users with pull-down boxes by which they would select a safety rating for the site. There was only one rating given per crosswalk, but three ratings per bicyclist approach. Once selected and submitted, the survey would proceed to the next site.

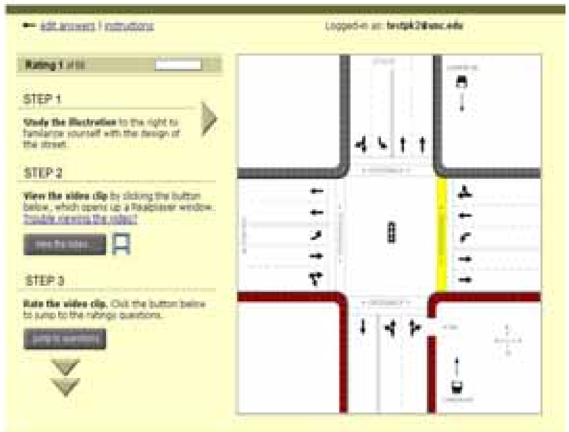


Figure 30. Top of pedestrian rating page.

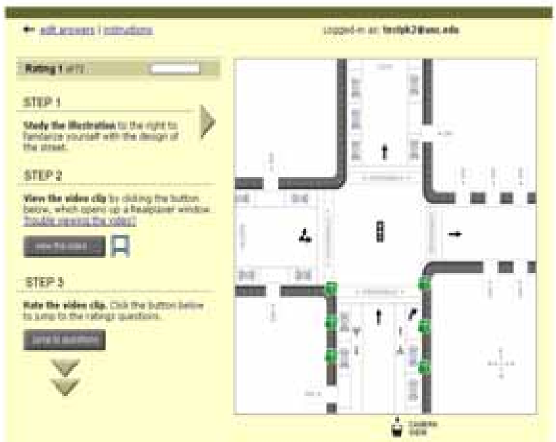


Figure 31. Top of bicycle rating page.

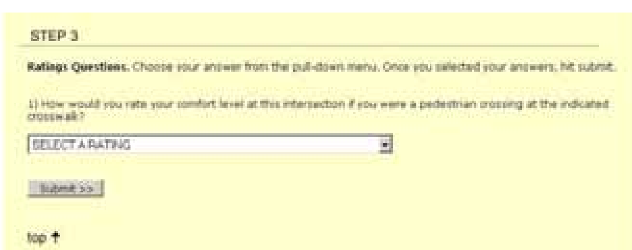
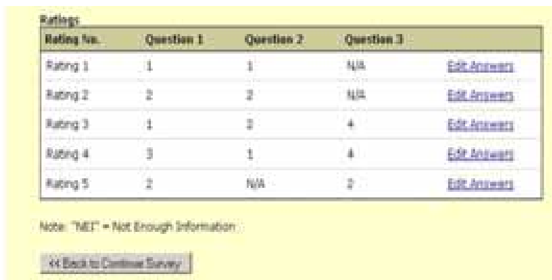


Figure 32. Bottom of pedestrian rating page.

Figure 33. Bottom of bicycle rating page.

Users were also given the option to change any rating previously placed (Figure 34 and Figure 35). This option was available at any point during the survey.



Ratings

Rating No.	Question 1	Question 2	Question 3	
Rating 1	1	1	N/A	Edit Answers
Rating 2	2	2	N/A	Edit Answers
Rating 3	1	2	4	Edit Answers
Rating 4	3	1	4	Edit Answers
Rating 5	2	N/A	2	Edit Answers

Note: "NEI" = Not Enough Information

<< Back to Continue Survey

Figure 34. Edit answers page for pedestrian survey.

Ratings

Rating No.	Answer	
Rating 1	2	Edit Answers
Rating 2	1	Edit Answers
Rating 3	3	Edit Answers
Rating 4	4	Edit Answers
Rating 5	1	Edit Answers

Note: "NEI" = Not Enough Information

<< Back to Continue Survey

Figure 35. Edit answers page for bicycle survey.

APPENDIX D. LESSONS LEARNED ABOUT ONLINE VIDEO-BASED SURVEYS

Through the process of creating and conducting the online safety survey, the research team encountered many issues related to Web-based surveys. Researchers who intend to conduct similar surveys may benefit from the lessons learned in this study. The online format was convenient for the ability to distribute the survey widely across the United States, and even internationally if needed. However, some survey participants only had dial-up Internet access, which caused the video clips to download very slowly. Some video clips were too small or of insufficient quality to provide ideal visibility of the intersection or crosswalk. Most of the issues encountered, however, came from the decision to distribute the video clips in RealPlayer™ format (".rm" files). In order to play RealPlayer video, it is necessary to download and install the free RealPlayer program. This program does not come pre-installed on most computer systems, unlike Microsoft® Windows Media® Player. The process of downloading and installing RealPlayer was confusing to many survey participants. Most city and State employees also had issues with firewall restrictions that prevented them from downloading and/or installing software on their computer. The research team recommends that future researchers create their video clips in a more easily read format, such as Windows Media (.wmv).

One of the difficulties in filming video clips of intersections is determining how to get the right vantage point to provide the viewer with all necessary information. Pedestrian crosswalks are relatively easy to film since they occupy only a small space in the intersection; however, bicycle approaches can be more difficult. It is often hard to strike the balance between positioning the camera too close (good detail of the intersection, but no view of the approach) and too far away (good view of the approach, but intersection details are unclear). Although this study used a single vantage point per clip, the research team suggests that including multiple vantage points would be a better alternative. For instance, the authors suggest a video clip design that would show the intersection from two or three positions, ranging from far away from the intersection to closeup. It might also be good to include a panning shot at the intersection to give participants a feel for the quality of the sight distance at the intersection.

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