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Development and Implementation of a Conflict-based Assessment of Pedestrian Safety (CAPS) to Evaluate Accessibility of Complex Intersections

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Abstract

This paper develops and implements the Conflict-based Assessment of Pedestrian Safety (CAPS) methodology for evaluating pedestrian accessibility at complex intersections. In past years, a significant research has been done on pedestrian access to modern roundabouts and other complex intersection forms, including a significant focus on the accessibility for pedestrians who are blind. A majority of these studies have relied on actual street crossings by study participants under supervision of trained Orientation and Mobility (O&M) Specialist. These crossing studies were used to evaluate risk from a measurement of *intervention* events, where the O&M specialist had to physically stop the participant from crossing.

While providing arguably the most accurate data for the crossing risk at a particular intersection, actual street crossings can be dangerous to the study participants, and are further very time consuming and expensive to conduct. The CAPS method presented in this paper emphasizes the use of conflict-based safety factors to quantify risk. The CAPS method relates pedestrian crossing decisions to advanced measurements of vehicle dynamics to estimate lane-by-lane conflicts. CAPS identifies the grade of conflict based on a score generated on a five-criterion rating scale. Each of these criteria or factors has different severity levels, and when combined, provides an overall risk rating of the crossing decision. The CAPS framework was applied to a study of blind pedestrian crossings at a multi-lane roundabout. The resulting risk scores were calibrated from

actual O&M interventions observed during the study to give confidence in the CAPS performance. The calibrated CAPS framework correctly matched all (high risk) O&M intervention events, and further identifies other (lower risk) pedestrian-vehicle conflicts.

The resulting method has the potential to allow for a faster and most importantly safer evaluation of complex intersections for pedestrian access. Since all factors are measured prior to the pedestrian stepping into the roadway, this approach is compatible with crossing indicator studies, where the participants merely indicate when they would cross, rather than actually stepping into the roadway. The CAPS framework therefore allows for a more objective and consistent safety assessment of pedestrian crossings in a research context without having pedestrians physically step into the roadway.

INTRODUCTION

Pedestrian facilities must be made accessible to all pedestrians, including those with vision or mobility impairments, as required by the American with Disabilities Act (ADA) (1). Pedestrians are vulnerable road users and are subjected to a higher risk than other road users (2). Modern roundabouts represent an intersection form that exhibits demonstrated safety benefits for motorized traffic (3) and further offers significant operational benefits over signalized or stop-controlled intersections in many applications (3). However, several recent studies have shown that roundabouts are not easily accessible by pedestrians, especially those pedestrians with vision impairments for three reasons: motorists fail to yield to pedestrians where the crossing is not signal controlled, noise from circulating traffic can make auditory detection of gaps difficult (especially at the exit), and gaps large enough to be aurally detected may be infrequent. (4, 5) As a result, the United States Access Board has drafted guidelines that call for the provision of accessible pedestrian-actuated signals at multi-lane roundabouts to make them accessible. There is concern in the engineering community that such general requirements will unnecessarily increase the cost of this very safe intersection form (6). Further, research has already identified non-signal treatments that may be adequate in some cases (7). The roundabout and accessibility community is in need of more research to evaluate and compare different crossing geometries, as well as the effectiveness of pedestrian crossing treatments (7). With (blind) pedestrian safety being the primary measure to evaluate accessibility, a study approach and evaluation framework is needed that can quantify pedestrian risk in a safe, objective, and consistent manner.

Most prior studies that evaluated the accessibility of complex intersections to pedestrians who are blind have relied on actual street crossings by study participants (8). The observational study of actual street crossings arguably gives the most accurate and realistic assessment of pedestrian safety, since study participants are truly interacting with motorized traffic. However, these studies carry some risk and participants must be monitored by a Certified Orientation and Mobility (O&M) specialist to satisfy requirements of Institutional Review Boards. Crossing studies are further time consuming and therefore expensive. Prior research was constrained to the evaluation of a limited number of test sites under limited research budgets. However, a recent national study aimed at identifying crossing solutions for pedestrians with vision impairments to roundabouts and intersections with channelized turn lanes concluded that a broader research approach is necessary to evaluate accessibility across a range of traffic operational and design characteristics (7). In other words, many additional sites need to be evaluated to be able to draw policy-impacting conclusions about which intersections may be accessible and which may require supplemental treatment installations.

This paper builds on extensive prior research experience with pedestrian crossing and indicator studies to develop a methodology that allows a safer and more efficient assessment

of the accessibility of an intersection. It builds on a vehicle-pedestrian conflict method for shared environments (9) and uses it to develop a conflict-based pedestrian safety assessment framework for multilane roundabouts. The conflict method is tested and calibrated using data collected on actual crossings of sighted and blind pedestrians. It can therefore be used to quantify crossing risk at a site for all categories of pedestrians.

The paper is structured as follows: the next section provides the basic framework of the study through review of various traffic conflict techniques. It also reviews prior research on blind pedestrian accessibility and crossing safety. The paper then describes the CAPS method of vehicle-pedestrian conflicts, the data collection method used in this study, and the modifications to the adapted vehicle-pedestrian conflict technique to be applied in the absence of real-world crossings. Following, the paper provides results from implementation of the modified vehicle-pedestrian conflict method. The paper concludes with a summary and recommendations for future research.

BACKGROUND

According to the most recent data available from National Highway Traffic Safety Administration (10) in year 2008, 37,261 fatal crashes took place across the United States, 4,378 (11.4%) of which were pedestrian fatalities. Crash data for pedestrians with vision impairments is less readily available, largely because of limited exposure, as blind travelers are likely to avoid many dangerous and inaccessible crossing locations. It is therefore infeasible (and indeed unethical) to rely on actual crashes to evaluate a crossing location in terms of the risk posed to blind travelers.

Nonetheless, the Americans with Disabilities Act (ADA) requires that new and altered facilities be designed and constructed to meet an equivalent ('accessible') standard. In the absence of a standard, the ADA requires a high degree of convenient usability by people who have disabilities. The draft Public Rights-of-Way Accessibility Guidelines (PROWAG) (6) set minimum criteria for meeting this legal requirement, thus serving as a safe harbor for designers (who may pursue other methods that can be shown to provide equivalent usability). The draft PROWAG presently stress the use of accessible pedestrian-actuated signals for multi-lane crossings at roundabouts and channelized turn lanes. Several research studies, including NCHRP 3-78a (7) and NIH/NEI Bioengineering Research Grant R01 EY12894-03 (8), aim to study and improve accessibility for visually impaired pedestrians at various facilities and under consideration of different types of infrastructure-based crossing treatments. Past studies evaluating treatments generally involved having blind participants cross at different locations, observing their crossing behavior under varying treatment conditions, and analyzing risky crossing decisions. These studies put participants in potentially risky and unsafe situations, and participants must at all times be accompanied by an O&M specialist to assure participant safety. A primary safety measure in this study is the *O&M Intervention*, which is defined as the O&M specialist physically stopping the participant AFTER he or she decided to step into the roadway to begin crossing. Clearly, these intervention events or pullbacks are important indicators of risk, but they are limited for several reasons. Interventions are:

- subjective, in that they are critically linked to one individual's perception of risk;
- binary, in that they can only distinguish between 'safe' and 'risky' without distinguishing between different levels of risk;
- dangerous, since they are the direct result of a potentially dangerous crossing decision.

Due to these limitations of the intervention measure, the development of a new safety measure framework is needed. That framework should allow for an objective assessment of risk across sites and participants, provide further scrutiny of different levels of safety, and reduce the risk for study participants. The use of pedestrian-vehicle *conflicts* represents a potential building block in such safety framework, provided that conflicts can be defined and measured objectively and consistently.

Several international studies were aimed at assessing traffic safety for different types of road users. Three well-known traffic conflict techniques are the “Swedish Traffic Conflicts Technique” (11), the “Institute of Highways and Transportation Conflicts Technique” (IHTCT) from the Transport and Road Research Laboratory in the UK (12), and the “US Department of Transportation Traffic Conflict Technique” (13). All define a conflict as a situation in which two or more road users approach each other in space and time in a way that evasive action must be taken in order to avoid a collision. All three frameworks take into account two major factors, namely *time to collision* and *speed* at the time of the conflict. Although the concepts underlying these methods are universally applicable across various modes of transportation, conflict analyses are most often applied to vehicle-to-vehicle conflicts.

Recognizing the viability of traffic conflict techniques to evaluate pedestrian safety, Kaparias et al. developed a vehicle-pedestrian conflict analysis method (9) based on IHTCT (12). The authors’ vehicle-pedestrian conflict analysis method was developed to evaluate shared vehicle and pedestrian spaces in the UK. The method uses four factors to describe different aspects of a conflict, with each factor further having different classes of severity. Based on the class of severity of each factor, a composite safety rating is obtained to classify the overall pedestrian-vehicle interaction event. The four factors in the Kaparias et al. framework are as follows (9).

- **Factor A, ‘time to collision’, (TTC)** is the time between an approach point and the potential collision between a pedestrian and a vehicle. TTC is illustrated in three classes of long, moderate, and short, with short being the most severe of the three classes.
- **Factor B, ‘Severity of evasive action’ (SEA)** is related to the value of deceleration rate. For pedestrians, this corresponds to different qualities of reaction to change course from walking to running or emergency action. Factor B has four classes of severity: light, medium, heavy, and emergency.
- **Factor C, ‘complexity of evasive action’ (CEA)** refers to the quality of action that the road user, pedestrian or vehicle, takes in order to avoid collision. Factor C has two classes: simple and complex.
- **Factor D, ‘distance to collision’ (DTC)** is the distance of the following vehicle from the point of conflict when an evasive action has taken place. Factor D has three classes: far, medium, and short.

In the Kaparias et al. (9) framework, all four measures are obtained from video observations of pedestrian crossings in shared-space environments. All four factors are qualitative. For example, time-to-collision is classified into three broad categories by an expert observer, rather than relying on actual measurements of vehicle dynamics (vehicle speed and position to the crossing point). This paper builds on the framework and adopts it to the application to controlled experiments of pedestrian accessibility at complex intersections.

OBJECTIVE

The objective of this research is to develop a method that can be used to efficiently and safely evaluate the accessibility of an intersection to various groups of pedestrians, including those with vision impairments. The Conflict-based Assessment of Pedestrian Safety (CAPS) method is compatible with indicator-based studies, in which visually impaired participants stand on the crosswalk and indicate when they would cross by raising their hand (14). At the same time, the method should provide detailed data on the interaction of pedestrians and vehicles that are sensitive to variations in pedestrian behavior, traffic operational parameters, and roadway design changes from one intersection to another, including the use of infrastructure-based crossing treatments. These objectives are motivated by findings and recommendations for future research of two multi-year research projects on the accessibility of complex intersections to pedestrians with vision impairments (7, 8)

METHODOLOGY

The CAPS framework consists of five safety factors that jointly describe the risk of a pedestrian-vehicle interaction event. Based on the severity level of each of these factors, a conflict grade is assigned to each crossing event. The conflict grade describes the risk level of the crossing decision on a quantitative scale from safe to very risky. The framework is intended for use in empirical research studies at pedestrian crosswalks at complex intersections, and geared at quantifying pedestrian risk during those studies. The five factors are measured from video or real-time data entry during the studies.

The CAPS risk factors are based on measures of vehicle dynamics, which are estimated at the instance the pedestrian steps into the roadway; or alternatively, at the time when the pedestrian indicates that he or she would cross. In this research, the framework was calibrated from actual crossings (with some interventions), but for future applications, all factors are compatible with indicator studies. A total of five factors are used to define various aspects of the pedestrian-vehicle interaction. They are combined to develop the composite safety score of the crossing decision. The five factors are defined as follows:

- **Factor A, “Time to Collision”.** Defined as the expected arrival time of the vehicle at the crosswalk given its instantaneous speed and relative position to the crosswalk. Time to collision (TTC) is calculated separately for each approach lane considering when the pedestrian would arrive in that lane based on his or her walking speed. TCC for each lane is calculated based on the formula below:

$$TTC(i) = \frac{d_{cw}}{V} - \frac{(LW) * (i - 1)}{V_p}$$

where,

- $TTC(i) (sec.)$: TTC for lane i, where i has levels 1, 2, and 3 for a three-lane and levels 1 and 2 for a two-lane crossing. Lane 1 is defined as the lane closest lane to the pedestrian or indicates intent to cross
- $d_{cw} (ft.)$: The distance from the vehicle to the crosswalk at the time pedestrian starts crossing
- $LW (ft.)$: Lane width of each vehicular travel lane.
- $V (ft/sec)$: Vehicle speed measured at the time the pedestrian starts crossing or indicates intent to cross

- V_p : (ft/sec): Pedestrian walking speed

According to this definition, TTC can take on a negative value. A negative TTC implies that the vehicle would have passed the collision point by the time the pedestrian reached the lane it is traveling in. In the CAPS framework, Factor A is divided into three classes with thresholds given in Table 1.

- **Factor B, “Severity of Evasive Action”.** This factor describes how much a driver would have to decelerate to come to a full stop before the crosswalk to avoid a collision with the pedestrian. Similar to TTC, it is calculated from the instantaneous speed and relative position of the vehicle at the time of a pedestrian event. In (9), the factor was defined qualitatively as light, moderate, sharp or sudden and uncontrolled. In this research, it has been converted to a continuous scale, since actual vehicle dynamics measurements are available. The necessary deceleration rate (DECEL) was defined as the rate of deceleration necessary for a vehicle to come to a full stop just prior to the crosswalk, given its current speed and position from the crosswalk (15). According to the Highway Capacity Manual 2000 (16), a reasonable range of deceleration rates for passenger cars varies between 7 ft/sec² and 26 ft/sec². Research shows that the maximum comfortable deceleration rate in non-emergency situations varies between 6.56 ft/sec² to 11.31 ft/sec² (2 m/sec² to 3.45 m/sec²) (16, 17). In emergency situations, the maximum deceleration rate varies from 16.40 ft/sec² to 27.88 ft/sec² (5 m/sec² to 8.5 m/sec²). Using the literature findings above, the thresholds for the four classes of Factor B are given in Table 2.
- **Factor C “Complexity of Evasive Action”.** This factor describes qualitatively any evasive action by pedestrian or driver that would signify a potentially risky interaction. The factor is largely consistent with (9) and is estimated by watching video recordings of the pedestrian crossing study. The factor has two levels, *simple* and *complex*, where the latter is any event associated with a vehicle swerving into adjacent lanes or a pedestrian jumping out of the way of an approaching vehicle.
- **Factor D “Distance to Collision”.** This factor describes the relative distance of the approaching vehicle to the crosswalk. The factor is divided into three classes and thresholds for the classes were estimated based on field observations at the test locations and under consideration of observed O&M interventions (Table 3).
- **Factor E “Lane Condition Factor”.** This last safety measure was added in order to describe the relative state of each conflicting lane. At a multi-lane crossing, the multiple threat crash type (18) is common, which is defined as a pedestrian entering the roadway in front of stopped or slowed traffic, and being struck by a moving vehicle in an adjacent, more distant lane. Similar to this crash type, stopped near-lane traffic in this study may visually and/or auditory mask traffic the second or third lanes. Factor E in the CAPS framework is assigned four classes based on the state of the vehicle in each lane at the time when the pedestrian initiates crossing. The vehicle state in each lane is defined as empty, stopped/yielding, or moving. A lane condition factor is developed based on the situation of each lane and it is presented in Table 4.

Developing an Overall Risk Score

Each of the five factors mentioned above have two to four levels, each providing a rank of the severity of the factor for each of the crossing events. To assess the overall risk score of a pedestrian crossing event, the five factors must be aggregated into a single numerical risk estimate. A conflict grade matrix to estimate this overall risk score was developed in (9), which shows different combinations of factors and assigns a conflict grade to each

combination. By taking into account the new factor E, the conflict grade matrix is revised and presented in Table 5. The modification consists of adding new combinations and assigning the proper conflict grade to those. Overall conflict severity increases from level 1 (slight) to 4 (severe).

In the application of table 5, the analyst reads the factor combination for a crossing event from the table to assign an overall safety score from 1 to 4. Alternatively, the authors developed a simplified method for determining the overall safety score by simple summation of the individual factors. The overall conflict grade is assigned based the levels shown in Table 6. Various attempts to weight the summation equation in favor of one or more factors did not result in notable improvements in model fit, and those results are therefore not presented here in the interest of space. The thresholds in Table 6 are shown for different combinations of factors A through E. While the full model (ABCDE) is likely to give the best results, attempts were made to simplify the CAPS model to fewer factors. This discussion will be provided in the presentation of implementation case study in the next section.

IMPLEMENTATION CASE STUDY

The CAPS method was implemented and calibrated from a dataset of actual pedestrian crossings collected at a multilane roundabout in the state of Michigan. This roundabout has two-lane approaches going north-south and three-lane approaches going east-west. With the distinction of the entry and exit portions of the crossing, a total of four conditions can be compared: two-lane entry, two-lane exit, three-lane entry, and three-lane exit.

Fourteen blind and six sighted individuals participated in this study. Each participant completed four trials at a two-lane and three-lane approach of the multilane roundabout. Each trial consisted of four crossings: curb to splitter island, splitter island to curb, curb back to splitter island, and splitter island back to curb. Therefore, each participant completed 32 crossings at the roundabout (16 at the two-lane and three-lane, respectively). In total, 224 crossings for blind participants and 96 crossings for sighted participants occurred on each approach. The actual number of crossings for some participants is less than 32 due inclement weather conditions or other factors.

Each participant was accompanied by an O&M specialist at each of the crossings. The O&M specialist intervened (by grasping the participant's arm or shoulder) if he or she perceived the participant to be at significant risk from approaching vehicles. These interventions are a key aspect of the team's safety evaluation. Interventions correspond to situations in which a collision appeared to be imminent during the crossing unless either a driver(s) or the participant took evasive action.

Vehicle dynamics measurements for the CAPS framework were facilitated by multi-angle video coverage, involving the use of three overhead video cameras and one ground-level video camera. An omni-directional camera was installed in the center island of the roundabout to obtain a 360 degree view of the roundabout. A camera was installed on both of the test approaches at a distance of approximately 300 feet upstream of the crosswalk. The omni-directional camera allowed the team to view the two exit approaches and the roundabout, while the two rear-facing cameras at each of the approaches allowed the team to see the entry legs of the two approaches. The ground-level camera was positioned at the crosswalk and also recorded sound from a wireless microphone used by the O&M specialist. All four camera views were synchronized in the office and recorded onto one common DVD with a split-screen view of all four video angles. These video discs were used to estimate vehicle-related measures such as distance to collision, speed, time to collision and required deceleration rate. Vehicle data were estimated for each vehicle that was in the approach of

the crosswalk when a pedestrian crossing decision was made. Figure 1 shows a screen shot of the composite video angle used for data collection in the office. A detailed video time-stamp and known distances obtained from field measurements were superimposed on the video during playback to estimate vehicle speed and position data. The dataset used to calibrate the CAPS framework was extracted from approximately 168 hours of video observations.

RESULTS

This section presents the results of implementing different combination of factors in the CAPS framework to the dataset. The objectives of this effort were to a) demonstrate the feasibility of the CAPS approach, and b) calibrate the optimal combination of factors in the framework. At the two-lane approach, 27.7% (58/209) of the crossings by blind participants took place when there was a moving car in either of the two lanes. For the three lane approach, 40.0% (89/222) of the crossings took place when there was a moving car in one of the three lanes. For the six sighted participants at the two-lane approach, 14% (14/96) of the crossings occurred when there was a moving vehicle in either of the lanes. For the three-lane approach, only, 10% (10/96) of the crossings took place when there was a moving vehicle in any of the three lanes. The rest of the crossings occurred when all lanes were either empty or had stopped vehicles. The threshold for considering an approach lane as “empty” was defined at a distance of 300 ft. (100 m) which corresponds to a time of approximately 10 seconds at a speed of 20 mph (30 ft/sec, 10 m/sec). In the CAPS framework, crossings that occur at times when all lanes are empty (or when all lanes have yielded) are defined to be safe. The relative risk of the remaining 171 events was evaluated using the five CAPS factors.

Table 7 shows the initial results of implementing the CAPS framework for two and three lane approaches for sighted and visually impaired participants. Those results are based on the original four factors A, B, C and D and the original conflict grade matrix from (9), but using the numerical thresholds developed in this study. The table also depicts the number of crossings that resulted in O&M interventions, which should be considered as very risky crossing decisions. Consequently, the expectation is that the framework should associate those with a severe conflict grade (grades 3 and 4).

The goal of the CAPS framework is to correctly predict the O&M intervention events with grades 3 and 4. Table 7 shows that sighted participants crossed only in conditions which are defined as grades 1 and 2 according to CAPS, which matches zero field-observed interventions for that group of participants.

For the visually impaired participants on the two lane approach, no crossings were associated with a Grade 4 conflict, and 7 out of 8 Grade 3 conflicts resulted in O&M interventions. From 41 Grade 2 conflicts, 4 of them also resulted in O&M interventions, as did one of the Grade 1 Conflicts. For the three-lane approach, the framework does not match all the interventions with severe conflict grade. The table shows that 5 out of 61 grade 1 conflicts resulted in O&M interventions. No interventions were associated with grade 2 conflicts. For the two more severe conflict categories, 9 of 15 grade 3 conflicts were associated with interventions, as were all 9 grade 4 conflicts. According to the results in Table 7, it is concluded that the four-factor approach and the use of original conflict grade matrix may not be sufficient for accurately identifying risky situations. Consequently, the combination of different factors including the new factor E is considered.

Table 8 shows different combination of factors that were tested to find an optimum framework. The various combinations are compared using measures of percent false

positives, percent false negatives, and the number of interventions that were missed by the framework (i.e. did not result in a rating of 3 or 4). The rate of false positives is calculated by dividing the number of non-interventions that resulted in a rating of 3 or 4 by the total number of interaction events. Similarly, the rate of false negatives is obtained by dividing the number of interventions that resulted in a rating of 1 or 2 by the total number of events. In other words, false positives describe non-intervention events that were categorized as risky, while false negatives describe actual interventions that were “missed” by the framework.

It is very important to reduce the value of false negatives to zero. Although the optimum combination is the one with the smallest false positive and false negative values, false positive values greater than zero only shows that model may overestimate risky and unsafe events. False negatives, on the other hand, mean that the framework missed a potentially risky event. A (systematic) false positive error is acceptable, since in the interpretation this simply makes the framework somewhat more conservative than the O&M intervention measures. Given the aforementioned binary nature of the O&M intervention measure, a greater frequency and distribution of risky events can be beneficial to get a more complete picture of the interaction. Table 8 shows the results for different combinations of factors using the conflict grade matrix presented in table 5. An attempt to replace that matrix by a single summation approach did not lead to improved results. For sake of brevity, only the conflict grade matrix results are given here.

An examination of Tables 8 and 9 indicates that the model with factors ABCDE using the conflict grade matrix yields the lowest fraction of false negatives for both two and three-lane approaches. A close second is model ABDE, which, while yielding some small fraction of false negatives, omits the use of the rather subjective factor “C”. The tables thus could assist future researchers to focus on those combinations that show promise in capturing the actual crossing conflict severity.

CONCLUSIONS

This paper developed and implemented the Conflict-based Assessment of Pedestrian Safety (CAPS) method to assess pedestrian accessibility at complex intersections, with the emphasis on the crossings of visually impaired pedestrians. The goal is to quantify the risk that pedestrians encounter at a particular crossing, while reducing the exposure risk during the study itself by using indicator-based studies instead of actual crossings. CAPS is based on measuring five factors, A, B, C, D and E (or possibly fewer) to define various aspects of pedestrian-vehicle interaction at the time the pedestrian indicates that he or she would cross. By classifying the severity level of each factor and using a conflict grade matrix, the severity of a potential conflict is identified. The proposed method was applied to actual street crossings of blind and sighted participants. The framework was calibrated using O&M intervention events, which are risky events where the experimenter had to physically stop a participant from crossing to avoid a potential collision. By calibrating the CAPS measures and thresholds to these documented risky events, confidence in the framework's ability to capture risk events is enhanced. In an attempt to further improve the method, the authors tested various combinations of the five factors and different aggregation approaches to arrive at an overall risk score. The results showed that the best match with field-observed O&M interventions is given by applying the revised conflict grade matrix to the combination of all five factors ABCDE. Alternatively, a model with factors ABDE that omits the use of the arguably subjective factor C, delivers a close second contender.

Future research is needed to validate the approach with crossings that were not used to calibrate the model, and to test the transferability of the approach to other sites and

geometries. In the interim, the results confirm the utility of conducting indicator studies that are likely to yield the same outcomes in terms of crossing conflict severity as do the more elaborate, costly, and potentially more dangerous crossing studies. Prior research already demonstrated the viability of indicator studies to measure pedestrian delay (19), and this contribution further formalizes their ability for a more comprehensive safety assessment.

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Figure 1.
Screenshot of Composite Video View of Test Site

Table 1

Thresholds for Factor A, Time to Collision

Factor A	Time to Collision (sec.)
Long [Class 1]	$TTC > 8, TTC < -2$
Moderate [Class 2]	$5 < TTC < 8$
Short [Class 3]	$-2 < TTC < 5$

Table 2

Thresholds for Factor B, Severity of Evasive Action

Factor B	Deceleration Rate (ft/sec ²)	Deceleration Rate (m/sec ²)
Light [Class 1]	DECEL < 6.56	DECEL < 2.0
Medium [Class 2]	6.56 < DECEL < 11.31	2.0 < DECEL < 3.45
Heavy [Class 3]	11.31 < DECEL < 16.40	3.45 < DECEL < 5.0
Emergency [Class 4]	DECEL > 16.40	DECEL > 5.0

Table 3

Thresholds for Factor D, Distance to Collision

Factor D	Distance to Collision (ft)	Distance to Collision (m)
Far [Class1]	DTC>100	DTC>30
Medium [Class2]	40<DTC<100	12<DTC<30
Short [Class3]	DTC<40	DTC<12

Table 4

Lane Condition Factor

a) Lane Condition Factor for <u>Two Lane</u> Approach			
Two Lane	L1:M	L1:S	L1:E
L2:M	4	3	2
L2:S	4	1	1
L2:E	4	1	1

b) Lane Condition Factor for <u>Three Lane</u> Approach for Lane 3, L3 (M/S/E)			
Three Lane	L1:M	L1:S	L1:E
L2: M	4/4/4	3/3/3	2/2/2
L2: S	4/4/4	3/1/1	3/1/1
L2: E	4/4/4	2/1/1	2/1/1

L1 refers to the near lane, L2 to the middle lane and L3 to the far lane with respect to pedestrian starting position. Vehicle states are defined as M: Moving, S: Stopped/Yielding and E: Empty. Lane condition factor is defined on the scale from 1 to 4, with 1 being safest and 4 being the most risky situation.

Table 5

Modified Conflict Grade Matrix Based on Adding the Lane Condition Factor - Modified from original in (9)

Factor	Grade 1 conflict														
A	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3
B	1	1	1	2	2	1	1	1	1	2	2	1	2	2	2
C	1	1	3	1	3	1	1	3	1	3	1	3	1	1	3
D	1	1	1	1	1	2	2	1	1	2	1	1	1	1	1
E	1	2	1	1	1	2	1	1	1	1	1	1	2	1	1

Factor	Grade 2 conflict														
A	1	1	1	1	1	1	2	2	2	2	2	3	3	3	1
B	1	1	2	2	3	3	1	1	2	2	3	3	1	1	1
C	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1
D	3	3	2	2	1	1	3	2	2	1	1	2	3	1	1
E	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2

Factor	Grade 3 conflict														
A	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3
B	2	2	3	3	1	2	2	3	3	3	2	2	3	4	1
C	1	3	1	3	3	1	3	1	3	3	1	3	1	3	1
D	3	3	2	2	3	3	2	2	3	3	2	3	2	1	2
E	3	3	3	3	2	3	2	3	3	4	4	3	4	4	4

Factor	Grade 4 conflict			
A	2	2	3	3
B	4	4	3	4
C	1	3	1	3
D	3	3	3	3
E	4	4	4	4

Table 6

Determining Grade of Conflict Based on the Summation of Levels of Factors

Model Combination	Specified range for summation of factors			
	Grade 1	Grade 2	Grade 3	Grade 4
ABCD	4-5	6-7	8-10	11-13
AE	2-3	4	5-6	7
BE	2-3	4-5	6	7-8
ABE	3-5	6-7	8-9	10-11
ADE	3-4	5-6	7-8	9-10
BDE	3-5	6-7	8-9	10-11
ABDE	4-5	6-7	8-10	11-14
ABCDE	5-6	7-9	10-12	13-17

Table 7

Results by Implementing Factors ABCD only

Number of:	Sighted		Visually Impaired	
	Two lane	Three lane	Two lane	Three lane
Crossings	96	96	209	222
Relevant Data points	14	10	58	89
O&M interventions	0	0	12	23
# Grade 1 Conflict - # Interventions	13-0	8-0	9-1	61-5
# Grade 2 Conflict - # Interventions	1-0	2-0	41-4	4-0
# Grade 3 Conflict - # Interventions	0-0	0-0	8-7	15-9
# Grade 4 Conflict - # Interventions	0-0	0-0	0-0	9-9

Table 8

Comparison of Different CAPS Model Combinations for Two-Lane Approach (n=58 events)

Model	% False Positive	% False Negative	Number of Missed Interventions (out of 12)
ABCD	1.8%	8.6%	5
ABCDE	4.3%	0.0%	0
AE	13.4%	0.0%	0
BE	12.9%	0.0%	0
ABE	13.4%	0.0%	0
ADE	13.9%	0.0%	0
BDE	19.1%	0.0%	0
ABDE	50.0%	0.0%	0

Table 9

Comparison of Different CAPS Model Combinations for Three-Lane Approach (n=83 events)

Model	% False Positive	% False Negative	Number of Missed Interventions (out of 23)
ABCD	6.7%	5.6%	5
ABCDE	9.0%	0.0%	0
AE	14.6%	10.1%	9
BE	19.1%	6.7%	6
ABE	49.4%	2.2%	2
ADE	50.6%	3.4%	3
BDE	19.1%	5.6%	5
ABDE	22.5%	1.1%	1