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Factors Influencing Pedestrian Decisions to Cross Mid-Block and Potential Countermeasures

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Final Report VTRC 25-R6

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 25-R6	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Factors Influencing Pedestrian Decisions to Cross Mid-Block and Potential Countermeasures		5. Report Date: November 2024
		6. Performing Organization Code:
7. Author(s): Kun Xie, Ph.D., Hong Yang, Ph.D., Sherif Ishak, Ph.D., Guocong Zhai, Ph.D., and Zizheng Yan.		8. Performing Organization Report No.: VTRC 25-R6
9. Performing Organization and Address: Old Dominion University 5115 Hampton Blvd. Norfolk, VA 23529	Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903	10. Work Unit No. (TRAIS):
		11. Contract or Grant No.: 120980
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final Contract
		14. Sponsoring Agency Code:
15. Supplementary Notes: This is an SPR-B report.		

16. Abstract:

About 70% of pedestrian fatalities involve mid-block crossings in Virginia. To address this critical safety issue, this research aims to investigate factors influencing pedestrian decisions to cross at mid-block locations and identify potential countermeasures to enhance pedestrian safety. The research team employed a multifaceted approach. A comprehensive literature review was conducted on factors affecting pedestrian crossing demand and choices and countermeasures to enhance pedestrian safety. Field data was collected from 1,150 pedestrians across 35 sites in Hampton Roads, Virginia. Additionally, 540 Virginia residents were involved in a survey to collect information on their crossing choices, human factors, and individual characteristics.

A hierarchical negative binomial model, designed to account for potential temporal variations, was developed to estimate hourly pedestrian crossing demand based on the collected field data. Furthermore, a multi-group structural equation model was developed to reveal the decision-making mechanisms behind pedestrian crossing choices using the survey data. Factors such as population, walk ratio, speed limit, number of lanes, sidewalk width, and land use interaction were found to affect crossing demand. Meanwhile, the presence of safety messages, traffic volume, number of lanes, travel time saved by mid-block crossing, and gender influenced crossing choices. Moreover, human factors like safety awareness and delay tolerance, which vary across demographics such as age and gender, were identified as key influences in explaining crossing choices. The crossing demand and choice models developed in this study can guide the identification of countermeasures, which are classified into two categories: 1) encouraging safe crossings at the nearby intersection crosswalk for mid-block locations with low crossing demand but high mid-block crossing probabilities and 2) improving the safety of mid-block crossings for mid-block locations with high crossing demand and high mid-block crossing probabilities.

This study recommends integrating quantitative models into pedestrian safety management processes. To facilitate implementation, the researchers developed an Excel-based tool, PedAct, which utilizes the crossing demand and choice models to inform decision-making in safety management, such as identifying locations with pedestrians exposed to high risk, developing countermeasures and evaluating their effectiveness. The PedAct tool has the potential to enhance the Virginia Department of Transportation's decision-making process in pedestrian safety management, ultimately reducing pedestrian crashes.

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17 Key Words: mid-block crossing, pedestrian crossing demand, hierarchical negative binomial model, multi-group structure equation model, recalibration.		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages:	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

November 2024
VTRC 25-R6

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ABSTRACT

About 70% of pedestrian fatalities involve mid-block crossings in Virginia. To address this critical safety issue, this research aims to investigate factors influencing pedestrian decisions to cross at mid-block locations and identify potential countermeasures to enhance pedestrian safety. The research team employed a multifaceted approach. A comprehensive literature review was conducted on factors affecting pedestrian crossing demand and choices and countermeasures to enhance pedestrian safety. Field data was collected from 1,150 pedestrians across 35 sites in Hampton Roads, Virginia. Additionally, 540 Virginia residents were involved in a survey to collect information on their crossing choices, human factors, and individual characteristics.

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This study recommends integrating quantitative models into pedestrian safety management processes. To facilitate implementation, the researchers developed an Excel-based tool, PedAct, which utilizes the crossing demand and choice models to inform decision-making in safety management, such as identifying locations with pedestrians exposed to high risk, developing countermeasures and evaluating their effectiveness. The PedAct tool has the potential to enhance the Virginia Department of Transportation's decision-making process in pedestrian safety management, ultimately reducing pedestrian crashes.

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INTRODUCTION

Pedestrians are the most vulnerable road users and are prone to a higher risk of injuries and fatalities when involved in traffic crashes compared with vehicle occupants.[1] According to the 2023 Virginia Department of Transportation (VDOT) Pedestrian and Bicycle Safety Action Plan, pedestrian fatalities in Virginia have increased dramatically to 111 to 122 per year since 2016.[2] Virginia has developed multiple action plans to address pedestrian safety issues, such as the Virginia (2022-2026) Strategic Highway Safety Plan, statewide Pedestrian and Bicycle Safety Action Plan (PBSAP), Bicycle and Pedestrian Safety Program under the Highway Safety Improvement Program (HSIP), and Safe Routes to School program. Despite these efforts, pedestrian crashes occurring at mid-block locations still raise significant concerns as some pedestrians prefer to cross at mid-block locations even though neighboring signalized intersections provide them with a pedestrian WALK phase.[3] Pedestrians crossing at uncontrolled mid-block locations could save travel time or distance but are exposed to a higher risk of being struck by motor vehicles. According to VDOT,[2] about 70% of pedestrian fatalities in Virginia involve mid-block crossings. Thus, it is critical to examine pedestrian crossing behaviors at mid-block locations and to investigate factors that drive pedestrians' decisions to cross. Generally, pedestrian crossing behavior is jointly influenced by various factors such as road geometry, traffic conditions, control and enforcement, land use, and pedestrian characteristics.[4-7] Fully understanding pedestrian crossing behaviors will help reveal the risk mechanism and support the development of appropriate countermeasures to mitigate crash risk.

PURPOSE AND SCOPE

The goal of this research was to investigate factors influencing pedestrian decisions to cross at a mid-block location without a marked crosswalk and identify potential countermeasures to enhance pedestrian safety. The researchers aimed to answer the fundamental question of why pedestrians cross at mid-block locations and to develop safety solutions accordingly. More specifically, the purpose of this research was to achieve the following objectives:

- Conduct a comprehensive literature review to summarize key factors affecting pedestrian crossing behaviors (i.e., crossing demand and choices of crossing locations), countermeasures (best practices and innovative solutions), and their effectiveness.
- Develop scientifically rigorous statistical models using field observation and survey data to understand what factors produce high percentages of uncontrolled mid-block crossings.
- Identify potential countermeasures that best address these factors to improve pedestrian safety.

This research focused on uncontrolled mid-block crossings, which expose pedestrians to a higher risk of crashes compared with crossings at signalized intersections. All mid-block crossings investigated in this project have marked crosswalks at nearby intersections as alternative crossing options. The criteria used to select mid-block crossings are detailed in the Method section. The emphasis of the study was on exploring factors linked with mid-block crossing behaviors. Field data on pedestrian crossing behaviors were collected mostly from priority corridors identified in the VDOT Pedestrian and Bicycle Safety Action Plan,[2] where pedestrians are prone to high safety risks. Data from other corridors were also collected to ensure representative samples were obtained. No field tests of specific countermeasures were involved in the current project. Instead, their proven effectiveness reported in other studies was summarized and documented. The survey data in this study focused on pedestrian crossing behaviors of Virginia residents.

METHODS

Overview

The following tasks were conducted to achieve the study objectives:

1. Review the Literature

2. Collect Field Data
3. Collect Survey Data
4. Develop Crossing Demand Models
5. Develop Crossing Choice Models
6. Identify Countermeasures

Figure 1 shows the framework of the methodology, which connects all tasks. The research team first conducted a comprehensive literature review on factors affecting pedestrian crossing behaviors and countermeasures to enhance crossing safety. In general, pedestrians choose to cross mid-block for two reasons: 1) the need to reach a destination on the other side of the roadways, and 2) mid-block crossing provides the best utility in terms of efficiency and safety compared with other alternatives (e.g., using the crosswalk at the nearest intersection). Accordingly, the researchers first developed **crossing demand models**, which estimated the crossing demand from factors such as land use, points of interest, pedestrian facilities, etc. Second, the researchers developed **crossing choice models**, which determined the probability of pedestrians crossing at mid-block at different times of the day based on a utility function with road geometry, traffic conditions, control and enforcement, and human factors as inputs. The researchers synthesized field observation data and stated preference survey data for model development and validation. Field data may capture contributing factors to real-world crossing demand, but due to the high cost of data collection in the field, it is difficult to cover a wide range of crossing scenarios (e.g., varying different median types and speed limits). Survey data can complement field data by enriching the crossing scenarios and taking more human factors into account. The crossing choice models developed based on survey data were validated with field observations. Potential countermeasures to address the unsafe crossing behaviors were recommended based on previous tasks.

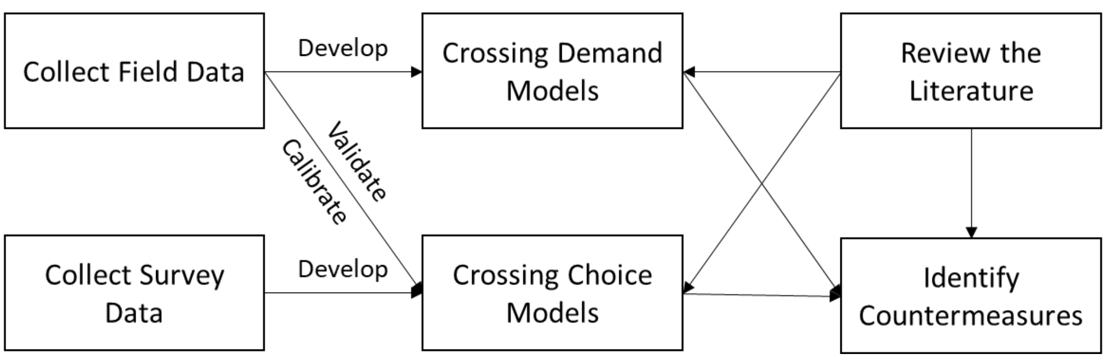


Figure 1. Methodology Framework

Review the Literature

The research team conducted a comprehensive literature review on factors affecting pedestrian crossing behaviors and the best practices for countermeasures to address crossing behavior concerns. This review focused on the reported facts documented in research studies, technical reports, or other published materials by agencies. The synthesis effort included:

- Summarized key factors affecting pedestrian crossing demand and choices pertaining to road geometry (e.g., number of lanes, presence of median, distance to the nearest marked crosswalk, sight distance), traffic conditions (e.g., traffic volume, composition, approaching speed), control and enforcement (e.g., pedestrian signalized control, advance warning signage, speed limit), environment (e.g., land use context, presence of transit stops, points of interest), and human factors (e.g., age, gender, pedestrian delay, gap acceptance, safety awareness);
- Summarized methods and their advantages and disadvantages for collecting pedestrian crossing data such as field observation, survey, and virtual reality experiments.
- Examined widely used countermeasures (e.g., high visibility crosswalks, advance warning signage), innovative countermeasures (e.g., rectangular rapid-flashing beacons, pedestrian hybrid beacon, and vehicle-to-pedestrian mid-block crossing warning), and their effectiveness in both improving pedestrian crossing safety (e.g., reducing pedestrian crashes) and changing behaviors of road users (e.g., increasing the yield rate, reducing approaching speed);
- Reviewed existing tools that could estimate pedestrian behaviors and identify countermeasures to enhance pedestrian safety.

Collect Field Data

To understand pedestrian crossing behaviors, this project collected real-world pedestrian crossing data from sample sites in Hampton Roads that vary in land use context, road geometry, traffic conditions, and traffic control. The criteria used to select sites include:

- Arterials and collectors
- Urban or suburban contexts
- Notable pedestrian generators/attractors present (e.g., sidewalks, shared use paths, or trails; transit stops or rail stations; medium to high density residential; schools or university campuses; parks or recreation centers; hospitals or health centers; libraries or senior centers; shopping centers, convenience stores, or restaurants; hotels or tourist destinations; and parking garages or convention centers)
- 300 ft or more to the nearest crosswalk (minimum requirement for installing crosswalks in IIM-TE-384.1[8]). Preferably over 600 ft in urban contexts and over 1000 ft in suburban contexts in site selections.
- High priority given to mid-blocks with pedestrian crashes (corridors of the VDOT Pedestrian and Bicycle Safety Action Plan, version 4).

Figure 2 shows an example of a site deemed suitable for field observation where there are adjacent office and commercial areas with considerable potential demand for pedestrian crossings. The observation point in blue was set between intersection crosswalks and where potential mid-block crossing could occur. Trained data collectors were required to stand at the observation point, ensure they could clearly see pedestrians crossing at intersections and mid-blocks in both directions and then manually document the attributes of each pedestrian. Data elements to be collected for each pedestrian included whether a crossing occurs, the choice of crossing location (intersection vs. mid-block), whether in a group, individual characteristics such as gender and age (based on the data collectors' best estimate), as well as traffic control information at the adjacent intersection (e.g., pedestrian delay, presence of pedestrian pushbutton), and potential near-miss incidents (identified by the best judgment of trained data collectors). For each site, the researchers continuously observed pedestrians for six hours, with the intention of covering the pedestrian behaviors in the daytime and nighttime. Due to varying sunset times, data collection occurred from 2 pm to 8 pm between November 24, 2022, and March 31, 2023 (daytime: 87 hours vs. nighttime: 63 hours) and from 4 pm to 10 pm during other collection periods (daytime: 32 hours vs. nighttime: 24 hours). Appendix A contains a field data collection form outlining the specific information gathered. The Institutional Review Board (IRB) application to collect pedestrian field data was approved on November 3, 2022.

Figure 2. Example of Field Observation (Little Creek Rd), Map Data ©2023 Google

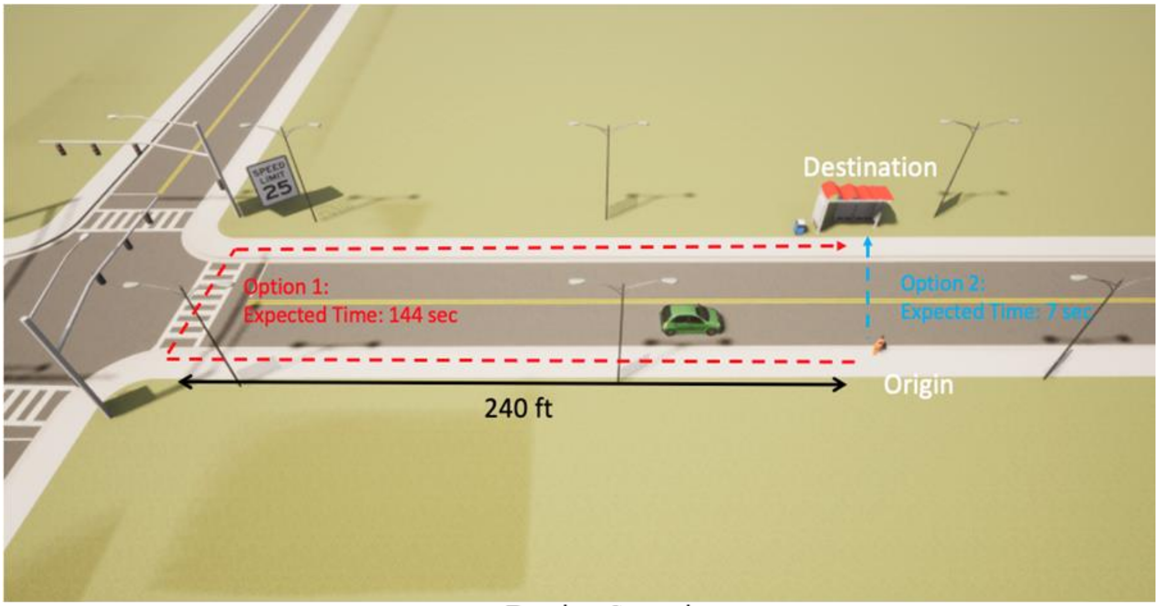
Collect Survey Data

A survey was designed to investigate crossing choices under a wide range of scenarios and to enable exploration of the relationship between human factors (e.g., safety awareness and delay tolerance) and crossing choices. The IRB application for conducting the survey was approved on April 26, 2023. To ensure high-quality survey outcomes, the Social Science Research Center at Old Dominion University (ODU), which provides professional services on survey design, data collection, and evaluation, was involved in administering the survey, and an internal pilot survey was conducted prior to the official launch. Appendix B provides details of the survey questionnaire. The survey instrument was divided into three steps as follows:

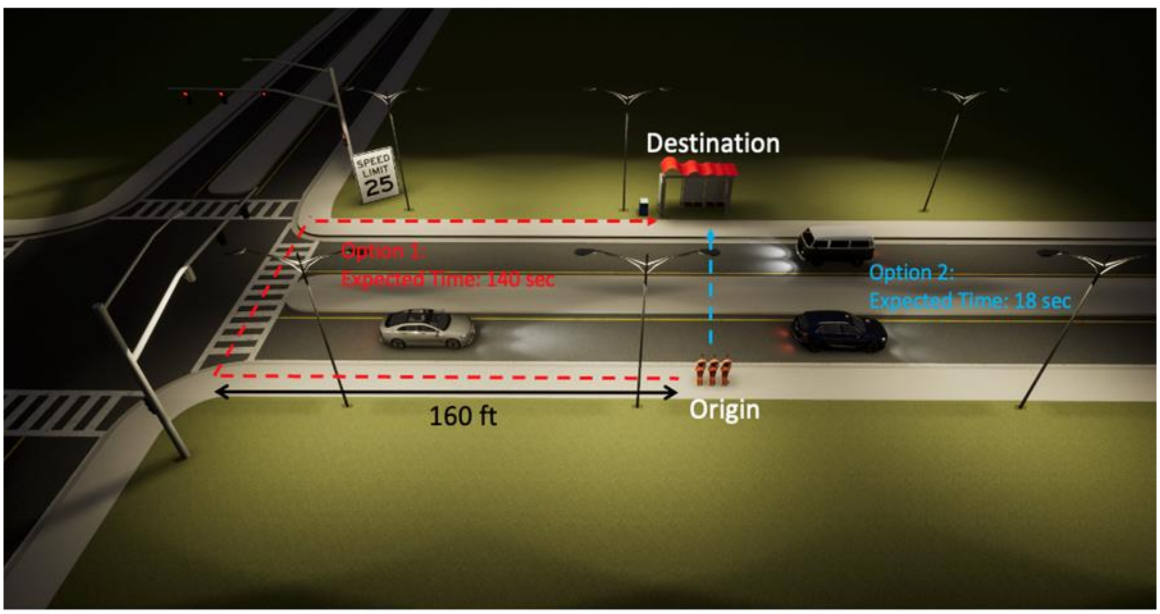
- **Step 1. Conduct a stated preference survey on crossing choices:** This step aimed to record participants' crossing choices in various hypothetical scenarios. A stated preference survey enabled the researchers to design controlled experiments and provided a cost-effective way to accommodate a wide range of scenarios. Key scenario-based variables affecting pedestrian crossing behaviors identified from the literature review were used to specify each crossing scenario, including *the presence of a median* (two levels), *distance to the nearest crosswalk* (three levels), *whether in a group* (two levels), *lighting condition* (two levels), *control type of the nearest crosswalk* (three levels), *traffic volume per hour per lane* (three levels), *number of lanes* (three levels), and *vehicle speed* (three levels). The eight scenario-based variables contribute to a total of 1,944 combinations. Thus, a fractional factorial design[9] was utilized to balance the scenario-based variables. The 19 most representative crossing scenarios were selected. A safety message was presented to randomly selected participants before the crossing scenarios: "*About 70% of pedestrian fatalities involve mid-block crossings in Virginia."* Each participant was required to respond to eight crossing scenarios, which were randomly selected from the pool of 19 scenarios in total. In each scenario, participants were provided with two crossing options: 1) **crossing at the nearest intersection crosswalk** and 2) **crossing directly at the mid-block location**. Participants selected one crossing option and indicated multiple reasons for their choice. Visual aids for the 19 crossing scenarios were designed to elicit the most realistic responses from participants. Figure 3 shows two examples of visual aids: one for daytime and one for nighttime. Rendering was used to depict different lighting conditions for the scenarios. Considering that the number of vehicles could have a psychological effect on crossing choices, the number of vehicles presented in each visual aid was determined based on the *traffic volume per hour per lane, number of lanes*, and *vehicle speed* in that scenario. Expected travel times associated with both options were presented to participants. The estimation of travel time is detailed in the following subsection.

- **Step 2**. **Assess human factors, including safety awareness and delay tolerance:** Participants were asked to answer attitudinal questions using a Likert scale to measure their safety awareness and delay tolerance, which are important human factors affecting crossing behaviors that could not be directly observed. An example question for measuring safety awareness is, "*How likely is it that you would cross a 6-lane street without a marked crosswalk and without a median?*" An example question for measuring delay tolerance is, "*At crossings where a pedestrian button is available, how likely is it that you would press it?*"

- **Step 3. Collect pedestrian characteristics:** Given they could affect human factors and crossing behaviors, participants' individual characteristics, such as age, gender, education, etc., were collected in this step.



Daytime Scenario



Nighttime Scenario

Figure 3. Visual Aids for Crossing Scenarios at Daytime and Nighttime

Travel Time Estimation for Both Crossing Options

Travel time is a critical determinant of pedestrian crossing choices.[10] Travel time is comprised of walking time and delay. If pedestrians choose to cross at the intersection crosswalk, it often involves a detour and thus takes a longer walking time compared to crossing directly at the mid-block. Pedestrians crossing at intersections may also experience delays due to traffic control. In this study, the researchers estimated pedestrian delay as half the pedestrian red interval at signalized intersections and ten seconds at stop-controlled intersections.

On the other hand, if pedestrians choose to cross at the mid-block location, they need to wait for sufficient gaps, and thus, the delay is affected by traffic volume, vehicle yielding behaviors, road geometry, etc.[11] The researchers adopted the established pedestrian delay calculation procedure developed in the NCHRP Report 312[11] to estimate the pedestrian delay at the mid-block location. Vehicle arrivals were assumed to follow a Poisson distribution. The research team adopted a yield rate of 0.4, a pedestrian walking speed of 4.4 ft/s along the sidewalk, and a crossing speed of 4.7 ft/s, as specified in NCHRP Report 312.[11] The ratio of pedestrians walking in a group was set to be 29%, according to the field observation survey.

Develop Crossing Demand Models

Data collected from the field observations were used to estimate hourly pedestrian crossing demand at the mid-block and the nearest intersection. Instead of developing Poisson models that assume equal mean and variance values, negative binomial (NB) and hierarchical negative binomial (HNB)[12, 13] models were adopted to address the overdispersion of crossing demand (i.e., lower mean value than the corresponding variance). In the field data collection, each site has six hourly crossing counts, constituting a hierarchical data structure. The HNB model can account for temporal heterogeneity of the hourly pedestrian crossing demand for the same observation site, which is anticipated to enhance model performance.

To develop the NB and HNB models for pedestrian demand, the explanatory variables considered involved these factors: demographics (i.e., walk ratio or transit ratio of commuting trips, population, senior ratio), land use context (i.e., land use interaction between two sides of the street, presence of a bus stop), road characteristics (i.e., the total width of sidewalks in both sides, presence of a median, number of travel lanes, lighting conditions), control and enforcement (i.e., presence of pedestrian push-button, traffic signal timing, and speed limit), temporal indicators (e.g., hour and whether it is nighttime), and weather conditions such as rain. In particular, the land use interaction denotes the interaction between dominant land use types of the two street sides (i.e., Education-Office, Green Space-Residential, Education-Residential, Office-Residential).

To formally define the pedestrian crossing demand models, y_{it} denotes the observed hourly pedestrian crossing demand of observation site i $(i = 1,2,3, \ldots, n)$ at hour t $(t = 14, 15, 16, \ldots, 22)$ and λ_{it} is the corresponding expectation of hourly pedestrian crossing demand. It is assumed that y_{it} follows a negative binomial distribution with the mean equal to λ_{it}, i.e., $y_{it} \sim NB(\lambda_{it})$.

In terms of the NB model, the hour indicator t is treated as a categorical variable affecting the hourly pedestrian crossing demand. Then, the NB model can be denoted as Equation (1):

$$\ln(\lambda_{it}) = \beta_0 + \boldsymbol{\beta}_1 \mathbf{X} + \beta_{\mathrm{t}} \mathrm{t} + \varepsilon_{it} \tag{1}$$

where **X** is a vector of contributing factors except for the hour indicator t. β_0 is a constant value, denoting the intercept in the NB model. $\boldsymbol{\beta}_1$ is a vector of corresponding coefficients of **X.** β_t is the coefficient of the hour indicator. exp (ε_{it}) is assumed to be gamma-distributed with a mean equal to 1 and a variance equal to α^2.

For the HNB model, the observed hourly pedestrian crossing demand y_{it} can be given by Equation (2):

$$\ln(\lambda_{it}) = \beta_{0\mathrm{t}} + \boldsymbol{\beta}_{1\mathrm{t}}\mathbf{X} + \varepsilon_{it} \tag{2}$$

where the coefficients β_{0t} and $\boldsymbol{\beta}_{1\mathrm{t}}$ are assumed to vary across the hour indicator t. In particular, $\beta_{0t} = \gamma_{00} + \varepsilon_{0t}, \varepsilon_{0t} \sim N(0, \sigma_0^2)$; $\boldsymbol{\beta}_{1t} = \boldsymbol{\Gamma}_{10} + \varepsilon_{1t}, \varepsilon_{1t} \sim N(0, \boldsymbol{\Sigma}^2)$. Other parameters are consistent with the NB model. The parameters of the NB and HNB models are estimated using the glmmTMB package in the statistical programming language R.[14]

Develop Crossing Choice Models

As indicated in Figure 1, crossing choice models were first developed using the stated preference survey data and then validated and/or calibrated using field data. The following two subsections address the model development and model validation and calibration, respectively.

Model Development

Structural equation modeling (SEM) was utilized to measure the latent human factors (i.e., safety awareness and delay tolerance) and capture the interrelationship among human factors, built environment, and crossing choices. The conceptual path diagram of the SEM for this study is shown in Figure 4. The underlying assumption is that pedestrians tend to maximize their crossing utility when choosing a crossing location (e.g., the mid-block location vs. the nearest crosswalk). The utility of pedestrian crossing is jointly affected by scenario-specific factors (i.e., road geometry, traffic conditions, control and enforcement), alternative-specific factors (i.e., travel time and distance of each alternative), and human factors (i.e., safety awareness and delay tolerance). The utility can be used to estimate the probability of mid-block crossing using a sigmoid function and thus formalizing the logistic regression.

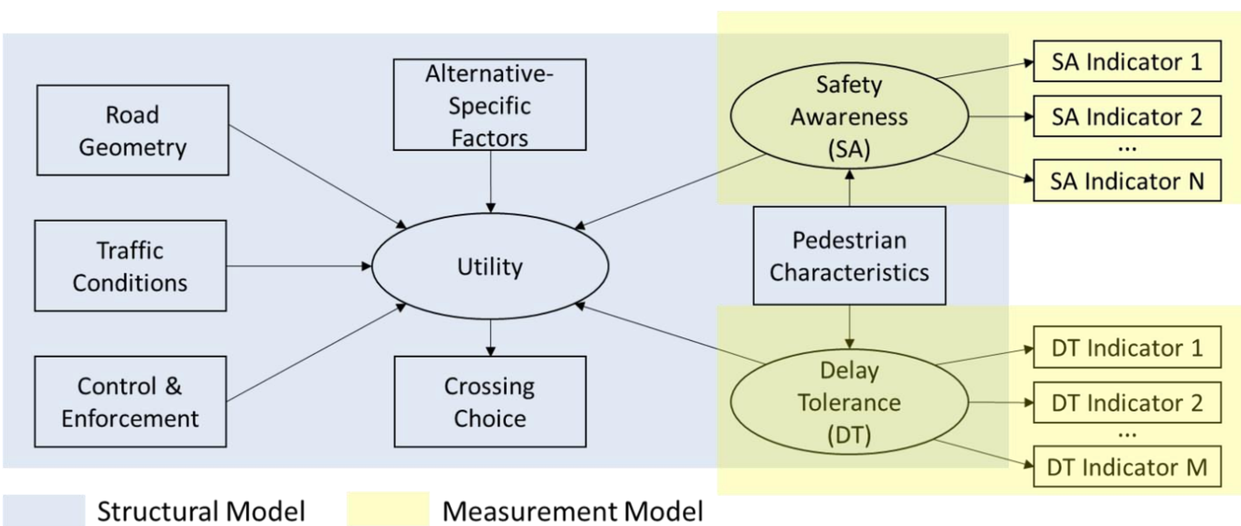


Figure 4. Conceptual Path Diagram for Crossing Choice Model

A multigroup SEM[15, 16] was developed to examine pedestrian crossing choices: at the mid-block location or at the nearest crosswalk. The reason for using a multigroup SEM is to capture the heterogeneity between daytime and nighttime while accommodating human factors such as delay tolerance and safety awareness. The researchers tested three model specifications[16]: 1) a multigroup SEM with equal thresholds, where the thresholds to determine crossing choices are held the same across groups with other parameters not constrained; 2) a multigroup SEM with equal regressions, where regression coefficients are held the same across groups with other parameters not constrained; and 3) a multigroup SEM with no constraint, where all parameters are not constrained and are freely estimated across groups.

As an illustration, the structural model of the SEM is expressed as Equation (3):

$$
\begin{aligned}
&\boldsymbol{y}_i^* = \boldsymbol{x}_i^{Sce}\boldsymbol{\beta}^{Sce} + \boldsymbol{x}_i^{Alt}\boldsymbol{\beta}^{Alt} + \boldsymbol{\gamma}_1\boldsymbol{SA}_i + \boldsymbol{\gamma}_2\boldsymbol{DT}_i + \boldsymbol{\varepsilon}_i^y \\
&y_i = 1, if\ y_i^* > \varphi, y_i = 0, otherwise \\
&SA_i = \boldsymbol{x}_i^{Ind}\boldsymbol{a}^{SA} + \varepsilon_i^{SA} \\
&DT_i = \boldsymbol{x}_i^{Ind}\boldsymbol{a}^{DT} + \varepsilon_i^{DT}
\end{aligned}
\tag{3}
$$

where i $(i = 1, 2, \ldots, N)$ is the index for crossing scenarios; y_i^* is the utility of crossing at the mid-block location; y_i is the observed crossing choice (0 for crossing at the nearest crosswalk, 1 for crossing at the mid-block location); $\boldsymbol{x}_i^{Sce}$ is a vector of scenario-specific factors including road geometry, traffic conditions, and land use and environment; $\boldsymbol{x}_i^{Alt}$ is a vector of alternative-specific factors indicating the additional cost at the nearest intersection crosswalk in terms of delay and travel distance; $\boldsymbol{x}_i^{Ind}$ is a vector of individual-specific factors such as age and gender; SA_i is a latent variable for safety awareness; DT_i is a latent variable for delay tolerance; $\boldsymbol{\beta}^{Sce}$, $\boldsymbol{\beta}^{Alt}$, $\boldsymbol{a}^{SA}$, $\boldsymbol{a}^{DT}$, γ_1, and γ_2 are regression coefficients; ε_i^y, ε_i^{SA}, and ε_i^{DT} are normally distributed error terms; and φ is a threshold to determine the crossing choice.

The measurement model of the SEM is formulated as Equation (4):

$$
\begin{aligned}
&\boldsymbol{I}^{SA} = \boldsymbol{SA}\ \boldsymbol{\Lambda}^{SA} + \boldsymbol{\delta}^{SA} \\
&\boldsymbol{I}^{DT} = \boldsymbol{DT}\ \boldsymbol{\Lambda}^{DT} + \boldsymbol{\delta}^{DT}
\end{aligned}
\tag{4}
$$

where $\boldsymbol{I}^{SA}$ is a $(N \times p)$ matrix of the responses to safety awareness questions in the human factor questionnaire, and $\boldsymbol{I}^{DT}$ is a $(N \times \mathrm{q})$ matrix of responses to delay tolerance questions in the human factor questionnaire; $\boldsymbol{SA}$ is a $(N \times 1)$ vector of the latent variable safety awareness, while $\boldsymbol{DT}$ is a $(N \times 1)$ vector of the latent variable delay tolerance; $\boldsymbol{\Lambda}^{SA}$ is a $(1 \times p)$ vector of factor loadings for safety awareness, and $\boldsymbol{\Lambda}^{DT}$ is a $(1 \times q)$ vector of factor loadings for delay tolerance; $\boldsymbol{\delta}^{SA}$ and $\boldsymbol{\delta}^{DT}$ are $(N \times p)$ and $(N \times q)$ matrices of gaussian errors. Mean- and variance- adjusted weighted least squares (WLSMV) estimator is robust for the estimation of models with categorical response variables[17] and thus was used to estimate the parameters of the multigroup SEM.

One advantage of SEM is that it can simultaneously measure latent variables like safety awareness and delay tolerance (in the measurement model) and estimate their interrelationship with other variables (in the structural model).[16] Participants' responses to the attitudinal questionnaire were used as indicators to measure safety awareness and delay tolerance. It was hypothesized that pedestrians with low safety awareness and low delay tolerance were more likely to cross mid-block. The SEM was expected to better represent pedestrians' decision-making than logit models by explicitly considering human factors.

Model Validation and Calibration

The multigroup SEM was then validated and calibrated using field observation data, which covered fewer crossing scenarios but reflected realistic crossing choices. All field data were used for validation to obtain an overall adjustment to the SEM. As an optional step, local data from one site were used for calibration to more reliably estimate the crossing choice probability at the targeted site for further analysis.

For each pedestrian crossing, the additional user cost at the nearest intersection crosswalk can be estimated based on origin-destination, crosswalk location, traffic volume, signal timing, median type, etc. Though human factor questionnaire data cannot be collected in the field, the pedestrian characteristics are sufficient to estimate safety awareness and delay tolerance using the SEM developed. The researchers used the Monte Carlo approach to generate pedestrian characteristics given the demographics at the census tract level. The generated pedestrian characteristics were used to estimate individuals' mid-block crossing probabilities. The researchers averaged the crossing probabilities at the mid-block crossing of all pedestrians.

The researchers proposed to validate the parameters of the multigroup SEM because of the choice difference between field observations and the stated preference survey. To preserve the relative relationship between contributing factors and utility, the researchers only chose to adjust the intercept of the utility function, keeping all the other parameters fixed. The objective function to validate the multigroup SEM was to minimize the absolute difference between the weighted average of the observed crossing probabilities and the weighted average of the estimated crossing probabilities at all mid-block locations. After the validation, the adjusted multigroup SEM yielded more reliable estimates of the crossing probability at the mid-block locations.

As an optional step, calibration aims to generate more accurate model outputs considering the heterogeneity across different sites. It should be noted that the parameter calibration is designed for one observation site to account for its heterogeneity and is only processed when the local data (i.e., pedestrian characteristics and crossing choices at the site of interest) is available. The objective function of the calibration process was to minimize the absolute difference between the observed crossing probability and the estimated crossing probability at the mid-block location.

Identify Countermeasures

This task identifies countermeasures with a proven track record based on a thorough literature review and outputs from the crossing demand and choice models. The literature review summarizes potential countermeasures to enhance pedestrian crossing safety along with their effectiveness, measured by crash modification factors. The crossing demand models estimate the hourly crossing demand, while the crossing choice models estimate the probability of mid-block crossings. Two categories of countermeasures are identified and considered:

1. **Countermeasures that encourage safe crossings at the nearby intersection crosswalk:** For mid-block locations with low crossing demand but high mid-block crossing probabilities, the researchers focused on countermeasures that encourage safe crossings at nearby designated crosswalks. This might include installing pedestrian signal buttons or reducing pedestrian delay at intersections.
2. **Countermeasures that improve the safety of mid-block crossings:** For mid-block locations with high crossing demand and high mid-block crossing probabilities, the researchers prioritized countermeasures that directly improve the safety of mid-block crossings. This could involve installing marked crosswalks, pedestrian refuges, or adding pedestrian signs and signals.

To facilitate the use of crossing demand and choice models for countermeasure development, **an Excel-based tool named PedAct was developed**. Excel was chosen to create the user interface because it is commonly available on VDOT computers. All parameters are implemented using basic Excel commands to ensure ease of use and accessibility for all users. The PedAct tool incorporates the crossing demand and choice models developed, which utilize input variables related to demographics, land use context, road geometry, traffic conditions, and control and enforcement measures. It outputs pedestrian crossing demand per hour and the probabilities of mid-block crossings during both daytime and nighttime, which can be used to categorize the site of interest (e.g., low crossing demand but high mid-block crossing probabilities, high crossing demand and high mid-block crossing probabilities) and thus aid the selection of countermeasures.

RESULTS

Review the Literature

This subsection reviews studies on pedestrian crossing demand, choices, and data collection approaches. It also summarizes countermeasures and their effectiveness in improving pedestrian crossing safety. Existing tools for analysis of pedestrian behavior and safety are also reviewed.

Pedestrian Crossing Demand

As summarized in Table 1, pedestrian crossing demand is affected by demographic factors (e.g., population density, employment density, lower-income population, and minority population), land-use context (e.g., land use diversity, development density, and the number of transit stations), road geometry (e.g., presence of sidewalks, the existence of a median, and road types), and traffic control and enforcement (e.g., posted speed limit).[18-24] Population density and employment density were found to have a positive impact on pedestrian demand and were used as surrogate measures in some studies when pedestrian volume data were unavailable.[25, 26] Low-income and minority populations were associated with higher pedestrian demand because of a higher likelihood of walking.[24, 27, 28]

Table 1. Summary of Contributing Factors for Pedestrian Crossing Demand and Choices

Variables		Pedestrian crossing demand	Pedestrian crossing choice
Demographics	Population density	+ 25, 26	
	Employment density	+ 25, 26	
	Low-income population	+ 24, 27, 28	
	Minority population	+ 24, 27, 28	
Land use context	Land use diversity	+ 29	
	Development density	+ 29	
	Number of bus stops	+ 26, 30	
	Number of education and research sites (e.g., universities and schools)	+ 31	
	Number of cultural and tourist facilities (e.g., exhibition hall, garden, and museum)	+ 31	
	Number of physical-activity-related facilities (e.g., sports facilities and medical treatment facilities)	+ 31	
	Number of residential communities	+ 31	
Road geometry	Presence of sidewalk	+ 32	
	Presence of a shade tree or place to sit and rest	+ 32	
	Raised median or refuge island	+ 33	+ 34, 35
	Arterial roads	+ 18	
	Crossing distance		- 36
	Adequate sight distance		+ 37
	Good lighting conditions		+ 38, 39
Traffic conditions	Traffic volumes		- 40
	Vehicle speed		- 40
	Presence of trucks or buses		- 41, 42
	Pedestrian speed		+ 43, 44
Control and enforcement	Posted speed limit	- 20	+ 10, 45, 46
	Pedestrian signal control		+ 47
	Crosswalk markings		+ 47
	Strong policy enforcement		+ 48
Human factors	Age		- 49, 50
	Male		+ 40
	Social conformity		+ 51-53
	Pedestrian perceived safety		+ 7, 36, 54
	Pedestrian perceived delay		+/- 4
	Pedestrian perceived convenience and comfort		+ 4

Notes:
+ increase crossing demand or likelihood of mid-block crossing
- decrease crossing demand or likelihood of mid-block crossing

In terms of the land use context, land use diversity and development density were positively related to pedestrian crossing demand.[29, 55] The number of bus stops/public transit stations was also positively associated with pedestrian crossing demand.[26, 30] The number of education and research sites (universities and schools, etc.), the number of cultural and tourist facilities (exhibition halls, gardens, zoos, museums, etc.), the number of facilities related to physical activities (sports facilities, medical treatment, governmental agency, etc.), and the number of residential communities were all found to have positive impacts on pedestrian crossing demand.[31]

For road geometry characteristics, the presence of sidewalks and shade trees or places to sit and rest were key components of pedestrian-friendly road environments,[56] leading to higher pedestrian crossing demand.[32] The presence of raised medians or refuge islands was also found to be positively associated with pedestrian crossing demand.[33] In addition, highways (interstates, US and state highways) and collectors were found to have lower pedestrian crossing demand than arterials.[18] Roads with higher posted speed limits were found to have lower pedestrian crossing demand.[20] Further, temporal variance by times of the day or days of the week in pedestrian demand was also observed by Singleton et al. (2021). [18]

The aforementioned factors were usually incorporated into direct pedestrian demand models, with functional forms such as linear (with cube-root transformation),[57, 58] log-linear (with spatial autocorrelations),[30, 32] negative binomial,[20, 59] Poisson,[60] and geographically weighted regression.[61]

Pedestrian Crossing Choices

Previous studies have found a variety of factors affecting pedestrian crossing choices, such as road geometry, traffic conditions, traffic control and enforcement, and human factors, as shown in Table 1.[4, 5, 7, 34, 36, 40, 47] For road geometry, the presence of a raised median or refuge island encourages pedestrian crossings at mid-blocks rather than waiting passively.[35] Crossing distance was found to have a negative impact on the likelihood of mid-block crossings.[36] A longer crossing distance increases the exposure to crashes and requires a larger gap in traffic, thus reducing mid-block crossings.[36] Adequate sight distance[37] and good light conditions[38,39] were found to encourage crossings at mid-blocks since safety perceived by pedestrians increased.[62]

In addition, traffic conditions characterized by traffic volume, vehicle speed, speed limit, vehicle types, and pedestrian speed were also considered in explaining pedestrian crossing choices.[7, 40-44, 54, 63, 64] Roads with higher traffic volumes and vehicle speeds were likely to have fewer mid-block crossings.[5, 40] The conflicts between large vehicles (i.e., trucks and buses) and pedestrians reduce pedestrian crossings.[41, 42] On the contrary, pedestrian speed was positively associated with mid-block crossings because a higher pedestrian speed implied an increased risk-taking attitude[43] and decreased pedestrian delay tolerance.[44]

Regarding control and enforcement, posted speed limits, pedestrian signal control, crosswalk markings, and policy enforcement significantly influence crossing choices.[10, 45-48] For example, higher posted speed limits are found to be negatively associated with mid-block pedestrian crossings due to the increased crash risks.[10] Similarly, higher traffic volumes are also found to reduce the propensity of mid-block pedestrian crossings.[45, 46] Mid-block crossings with pedestrian signal control and crosswalk markings were found to have more pedestrian crossings.[47] Stronger policy enforcement on motorists (e.g., must yield to pedestrians) also leads to more pedestrian crossings.[48]

Human factors (e.g., age, gender, and pedestrian attitudes) were found to be determinants of pedestrian crossing choices.[3, 7, 51] For example, senior pedestrians were found to have lower walking speeds[65] and situational awareness of the road environment,[66] reducing the ability to perceive and respond to unexpected safety events. Correspondingly, elderly pedestrians were less likely to cross at the mid-block to compensate for their reduced ability.[49, 50] In contrast, children were found to have more mid-block crossing behaviors, even when accompanied by adults.[50] Males were also more likely to choose to cross at mid-blocks crossing decisions.[7] Because of social conformity, pedestrians tended to cross the street in a group, regardless of legality or safety.[51, 52] Pedestrians' gap acceptance choices indicated their assessment of how safe it was to cross via an available gap and could be used to reflect their perceived safety.[7, 54] The perceived delay of pedestrians was found to impact mid-block crossings with lower traffic volumes positively and impact mid-block crossings with higher traffic volumes negatively.[4] The convenience and comfort of the mid-block crossing were also perceived to affect pedestrian crossing choices positively.[4]

Previous studies explored pedestrian crossing choices using descriptive analyses[40, 49, 67] and discrete choice models, including binary logit models,[68] multinomial logit models,[7] and mixed sequential logit models.[5]

Data Collection Approaches

Pedestrian crossing demand was usually gathered from automated counting, manual counting, and new data sources (e.g., mobile phone data and traffic controller events).[18, 33, 69, 70] Despite the capability to observe pedestrians continuously, automated count devices are expensive to deploy and maintain on a large scale. Manual counting approaches are more flexible but can only collect pedestrian demand data in a short period of time.[71] New data sources, such as mobile phone signalizing data and traffic controller events[72] provide an economical and scalable way to estimate pedestrian crossing demand at large spatial and temporal scales. The most challenging issues of new data sources were their accuracy and reliability.

In addition, data for pedestrian crossing choices were generally collected by field observations, surveys, and virtual reality experiments.[4, 7, 63] Through video recordings, field observation helps gather pedestrians' natural behaviors.[68] However, it can only cover limited scenarios due to the uncertainty of pedestrian presence and high cost,[47] and may not provide sufficient information on pedestrian attitudes and perceptions.[73] In contrast, surveys are more affordable, can cover more crossing scenarios by stated preference experiments, and can probe into pedestrian attitudes and perceptions.[74] Survey data may be prone to self-reporting bias and selection bias.[4] Virtual reality (VR) experiments could offer participants an immersive environment and facilitate the making of crossing choices similar to reality.[63, 75, 76] However, it is costly to construct a large number of virtual crossing scenarios and involve many participants.

Countermeasures to Improve Pedestrian Crossing Safety

Table 2 summarizes the crash modification factors (estimated by the crash frequency after the treatment divided by the crash frequency before the treatment) of countermeasures for improving pedestrian crossing safety at mid-block locations. Typical countermeasures to address pedestrian crossing concerns can be classified into two categories: infrastructure and design and control and enforcement.[77, 78] Infrastructure and design measures include treatments like raised medians or pedestrian refuge islands, raised crosswalks, curb extensions, road diets, narrow lane widths, pedestrian overpasses, pedestrian underpasses, corridor-wide speed calming, and enhanced illumination at pedestrian crossings.[79, 80] For example, curb extensions directly shorten crossing distances and reduce the exposure of pedestrians to crashes, with a 3%-8% improvement in yield rates.[81] Widely used traffic control devices to improve the safety of pedestrian crossings include high-visibility crosswalk markings, advance stop/yield bars markings or signs, pedestrian hybrid beacons, rectangular rapid flashing beacons, overhead or roadside-mounted flashing beacons, pedestrian warning signs, parking restrictions, and in-pavement flashing lights.[79, 80] For example, rectangular rapid flashing beacons are designed to increase the awareness of drivers and thus provide a safer environment for pedestrians to cross. Vehicles that are parked too close to the midblock crossing block sight lines between drivers and pedestrians. Parking restrictions could improve pedestrian and driver sight lines by eliminating parking from the roadway near the mid-block crossing.[79] Prior studies found no significant difference in crash modification factors between high-visibility and basic crosswalk markings, but high-visibility crosswalks lead to increased yielding behaviors of drivers.[82] In-pavement flashing lights/flashing crosswalks and overhead or roadside-mounted flashing beacons also improve yield rates.[79, 83] In addition, the marked crosswalks alone do not necessarily reduce crashes, partly because of interactions with other roadway characteristics (e.g., wider roadways, undivided crossings, and arterials) that can increase risk.[8, 84] As suggested by VDOT,[8] additional countermeasures beyond just markings are recommended as roadway-related risks increase. A possible reason could be that marked crosswalks encourage more pedestrian crossings regardless of conflicts with heavy traffic.[84] A driver-yielding enforcement program reduces vehicle operating speed and pedestrian waiting time.[85] Emerging technologies such as pedestrian crossing warnings from connected and automated vehicles (CAVs) might also be alternative approaches to improve pedestrian safety. However, the safety effectiveness of these two countermeasures was still unavailable according to the current literature.

Table 2. Summary of Countermeasures to Improve Crash Safety at Mid-Blocks

Countermeasures	Crash Modification Factors			References
	Pedestrian Crashes	All Crashes	Fatal or Injury Crashes	
Infrastructure and design				
Raised median or refuge islands	0.54-0.75	0.74		80, 86, 87
Raised crosswalk/speed table	0.55	0.70	0.64	88, 89
Road diet (roadway reconfiguration)	0.38	0.53-0.81	0.27	90-92
Narrow lane width		0.71		92
Pedestrian overpass/bridge	0.10-0.14			93, 94
Pedestrian underpass/tunnel	0.10-0.14			93, 94
Corridor-wide speed calming			0.75-0.90	95
Enhanced illumination at crossings	0.58-0.80		0.58-0.77	33, 95, 96
Control and enforcement				
Crosswalk markings (with high visibility)	0.52-0.63	0.81		90, 97
Advanced stop/yield bars or signs	0.64-0.86			80, 98
Pedestrian hybrid beacon	0.24-0.43	0.71-0.82	0.85	80, 98, 99
Rectangular rapid flash beacon	0.53	0.93		79, 80, 98
Pedestrian warning signs		0.85-0.96		83, 100
Parking restriction	0.70			79
Driver-yielding enforcement	0.77			85

Tools for Pedestrian Behaviors and Safety

The Areawide Exposure Tool developed by the Federal Highway Administration can provide estimates of pedestrian demand at areawide levels.[22] The Areawide Exposure Tool requires numerous input variables, including daily persons commuting by walking, adjustment factors for commute-to-total trips, population adjustment factor, and average trip length. In addition, the Pedestrian Safety Guide and Countermeasure Selection System were designed to identify countermeasures based on performance objectives (e.g., improving safety at uncontrolled crossings and eliminating behaviors that lead to crashes) or targeted crash types (e.g., backing vehicle and bus-related).[101] The inputs of the Pedestrian Safety Guide and Countermeasure Selection System include road types, traffic volumes, vehicle speed, the number of lanes, etc. Similar to the Pedestrian Safety Guide and Countermeasure Selection System, the Pedestrian and Bicycle Crash Analysis Tool can also identify possible countermeasures to reduce specific pedestrian crashes.[102] The Pedestrian and Bicycle Crash Analysis Tool mainly focuses on crash-type-based treatments, which require more detailed crash information such as crash locations, crash occurrence time, characteristics of victims involved (age, gender, injury severity, etc.), and maneuvers of the road users involved.

Collect Field Data

According to the site selection criteria discussed in the methodology section, the researchers selected 35 sites in Hampton Roads to collect field data on pedestrian crossings. The selected sites vary in the number of lanes at mid-block, speed limit, presence of a raised median, presence of a bus stop, the total width of both sidewalks, and land use interactions. The characteristics of selected sites are detailed in Appendix C. Figure 5 presents the locations of the selected sites.

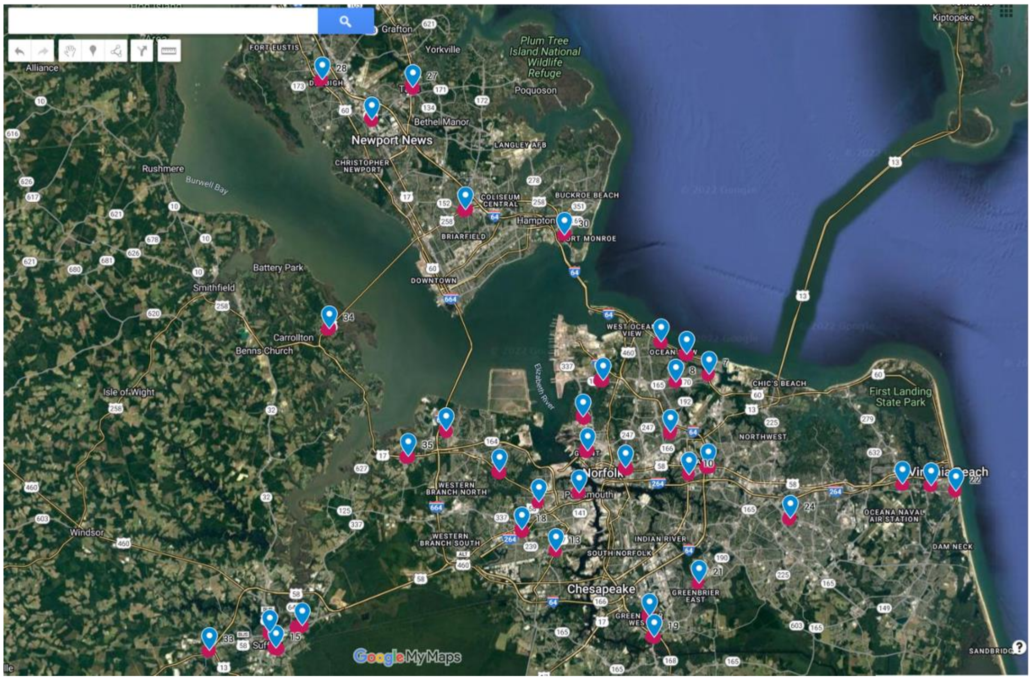


Figure 5. Field Observation Sites, Map Data ©2023 Google

Trained data collectors identified pedestrian demographic features such as age and gender based on their best judgment. Figure 6 presents the distributions of these demographics. Pedestrian age is categorized into four groups: child (<18), adult (18-65), senior pedestrian (>65), and unsure. Among the 1,150 observed pedestrians, only 57 were seniors estimated to be over 65, and 139 were young people estimated to be under 18. Additionally, more male pedestrians were observed than female pedestrians.

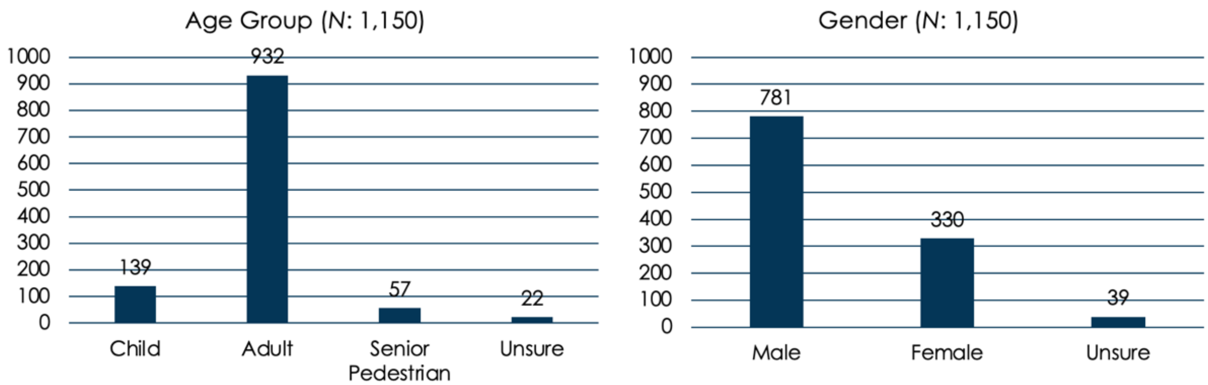


Figure 6. Observed Pedestrian Demographics

Data collectors also observed various pedestrian behaviors, such as whether walking in a group, crossing occurrence, crossing locations, crossing locations by walking in a group, crossing choices at daytime and nighttime, and crossing strategies (i.e., single-stage vs. multi-stage), as shown in Figure 7. Among the 1,150 observed pedestrians, 720 crossed the streets, while 430 walked along the sidewalk and did not attempt to cross. Out of these pedestrians who crossed the streets, the proportion of mid-block crossing was 45.97% (i.e., 331/720). There were 269 (98+171) pedestrians crossing the streets in groups, with a mid-block crossing proportion of 36.43% (98 out of 269). In contrast, 451 (233+218) pedestrians crossed the streets alone, with a mid-block crossing proportion of 51.66% (233 out of 451). Pedestrians were more likely to cross at mid-block when they were walking alone. Additionally, data collectors noted a higher proportion of mid-block crossing in the daytime (54.19%) than at night (52.38%). Regarding crossing strategies, 195 pedestrians used multi-stage crossings, while 525 crossed the street in a single stage.

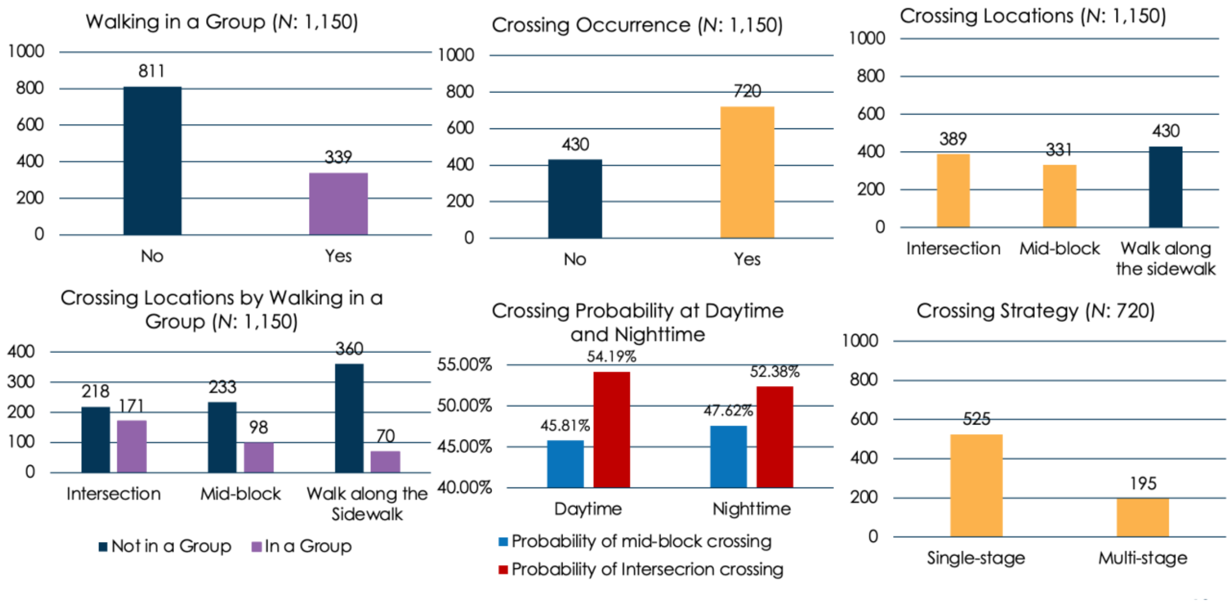


Figure 7. Observed Pedestrian Behaviors

No crashes were observed during observation periods. Figure 8 illustrates the proportion of pedestrian crossings that involved near-miss incidents. Out of 720 pedestrians who crossed the street, it was observed that near-miss incidents were more likely to occur at mid-block locations compared to intersections. Additionally, the data indicates that pedestrians were at a higher risk of near-miss incidents during nighttime compared to daytime. This suggests that both the location and time of crossing significantly impact pedestrian safety.

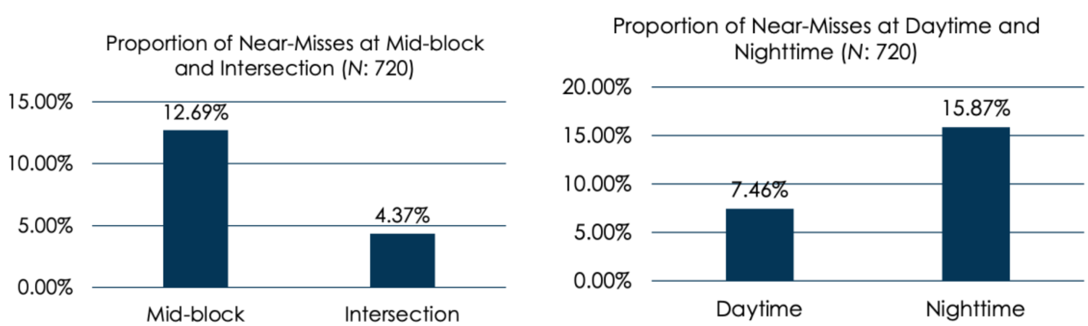


Figure 8. Proportions of Pedestrian Crossings Involving Near-Misses

Figure 9 presents the histogram of the number of crossing pedestrians each hour from all selected sites. The distribution shows that the hourly pedestrian crossing demand is over-dispersed, presenting a much lower mean (3.5) than the variance (26.32). This over-dispersion in pedestrian crossing demand makes accurate prediction challenging.

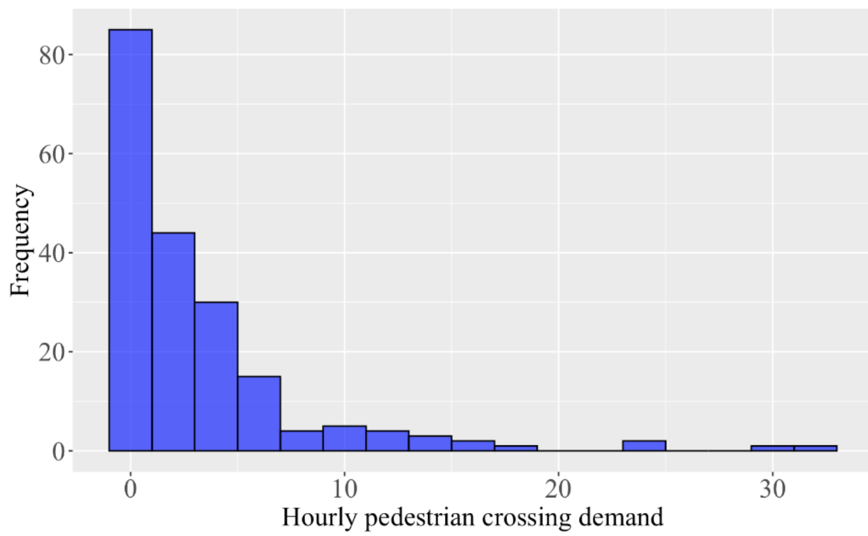


Figure 9. Histogram of Hourly Pedestrian Crossing Demand

Collect Survey Data

A total of 540 Virginia residents aged 18 or older participated in the survey. The safety message was presented to 303 participants. The average time for completing the survey was about eight minutes. Each crossing scenario received between 223 and 232 responses. There were ten daytime crossing scenarios with mid-block crossing probabilities ranging from 11.30% to 33.48%. In contrast, there were nine nighttime crossing scenarios with mid-block crossing probabilities ranging from 13.84% to 32.33%. The average daytime mid-block crossing probability is 20.52%, about the same as the average nighttime mid-block crossing probability of 20.28%.

Figure 10 presents the reasons for choosing different crossing locations. The predominant reasons for crossing at the intersection crosswalk were enhanced safety and responsible behavior. Conversely, the primary reasons influencing the decision to cross at mid-block locations were the shorter distance and time required.

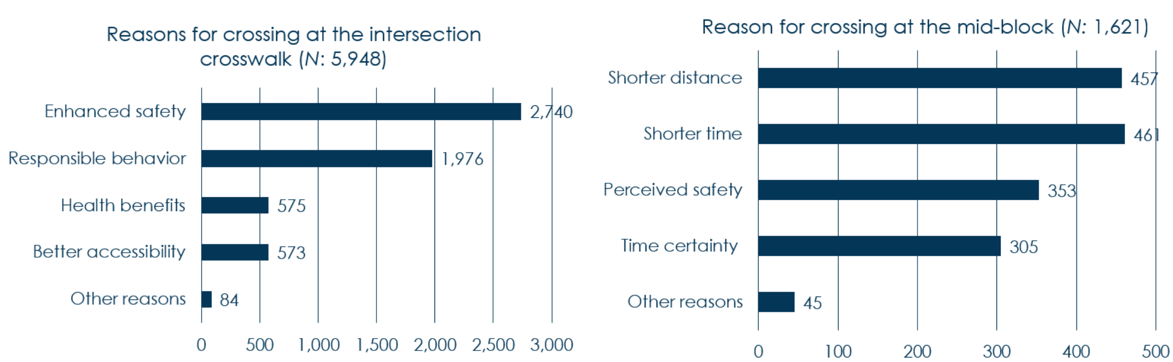


Figure 10. Reasons for Different Crossing Choices

Human factors, including safety awareness and delay tolerance, cannot be directly observed. Thus, the researchers used attitudinal questions (Q1-Q5) to measure safety awareness and delay tolerance (Q6-Q9). Take questions Q1 and Q8 as an example. Pedestrians with higher safety awareness will likely not cross a 6-lane street without a marked crosswalk and without a median. Pedestrians with lower delay tolerance tend to run along a marked crosswalk during a WALK phase if they are in a hurry. The participants' responses to these questions are depicted in Table 3.

Table 3 Responses to Questions on Safety Awareness and Delay Tolerance

Questions	L5	L4	L3	L2	L1
Safety Awareness					
Q1. How likely is it that you would cross a 6-lane street without a marked crosswalk and without a median?	23	40	59	137	281
Q2. How often do you follow the signs and signals when crossing the street?	245	205	70	15	5
Q3. How often do you use your cell phone while walking across the street?	17	23	111	171	218
Q4. How often do you walk in the roadway alongside traffic even when sidewalks are available?	23	26	66	117	308
Q5. How often do you cross a street without actively looking for cars as you cross?	21	31	34	51	403
Delay Tolerance					
Q6. At a traffic light, how likely is it that you would cross a street when no traffic is coming and the solid "Don't Walk" or red light is on for pedestrians?	42	117	111	120	150
Q7. At crossings where a pedestrian button is available, how likely is it that you would press it?	330	131	44	23	12
Q8. How likely is it that you would run along a marked crosswalk during a WALK phase if you are in a hurry?	79	179	140	87	55
Q9. How likely is it that you would pay $5 for a shuttle bus to reduce walking time by 20 minutes?	72	152	128	106	82

Notes: L5 denotes extremely likely or always, L4 denotes likely or often, L3 indicates sometimes or neutral, L2 denotes unlikely or rarely, and L1 denotes extremely unlikely or never.

Figure 11 presents the demographics of the survey participants. Due to IRB restrictions on surveying teenagers, the researchers focused on participants aged 18 and over. Among the 540 participants, only seven were aged 65 and over, while 131 were aged between 50 and 65. Furthermore, there were more female participants compared to male participants. Additionally, white individuals were the dominant race among the participants, followed by African American and Asian individuals. Most participants possessed a driver's license, likely reflecting the car-oriented development strategy in the United States. Approximately 25% of participants had earned a bachelor's degree or higher. Furthermore, 47 participants had experienced motor vehicle crashes while walking across the street. Most participants owned at least one vehicle per household, and only 63 participants reported an annual personal income of less than $15,000.

Figure 11. Demographics of the Survey Participants

Figure 12 highlights the influence of the safety message (i.e., presenting the pedestrian fatality statistics related to mid-block crossing) on pedestrian crossing choices. The presence of the safety message reduced the percentage of mid-block crossing from 21.89% to 19.22%, a reduction of 2.67%. This indicates that warning pedestrians about the risks of mid-block crossing could effectively change their behaviors and enhance their safety. The statistical significance of the safety message was further evaluated using quantitative models (see the subsection Develop Crossing Choice Model).

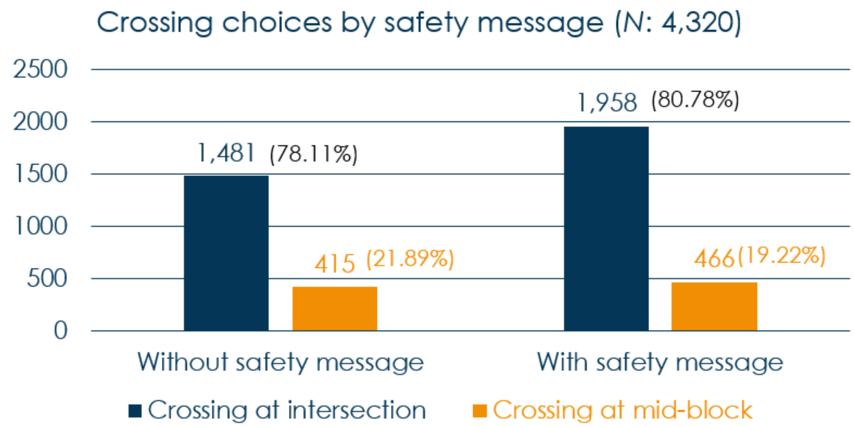


Figure 12. Crossing Choices Affected by the Safety Message

Develop Crossing Demand Models

The NB and HNB models were developed to estimate the hourly pedestrian crossing demand. Table 4 summarizes the performance metrics. Figure 13 visually depicts the relationship between predicted and observed demand for both models. The HNB model was found to outperform the NB model based on Mean Absolute Error, Mean Absolute Percentage Error, and pseudo-R squared. Consequently, the HNB model was chosen for further analysis due to its superiority. The crossing demand is over-dispersed (as shown in Figure 9) and affected by a wide range of factors (as shown in Table 1), making it challenging to predict accurately. The goodness of fit for the crossing demand models can be further improved with additional data and by exploring non-linear functional forms in general perspectives.

Table 4. Performance Metrics of the Crossing Demand Models

Measurement Metrics	**Hourly Pedestrian Crossing Demand Model**	
	NB	**HNB**
Mean Absolute Error (pedestrian/hour)	2.80	2.59
Mean Absolute Percentage Error	0.78	0.72
Pseudo R-squared	0.29	0.41

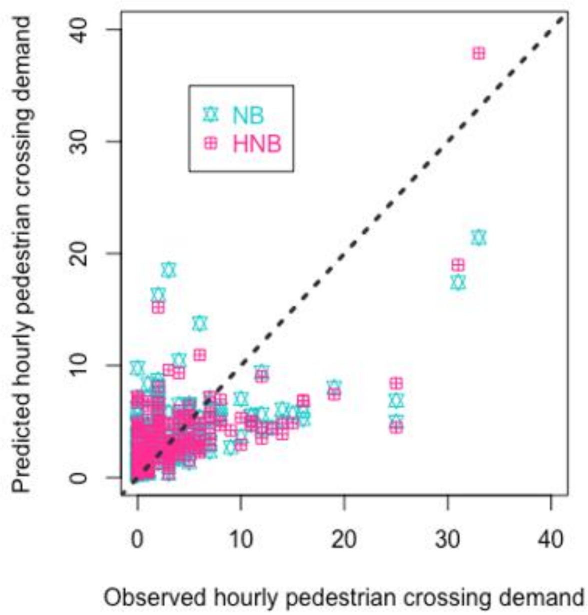


Figure 13. Comparisons between the Predicted and Observed Hourly Pedestrian Crossing Demand

Table 5 reports the parameters of the HNB model, involving the fixed regression coefficients and temporal random effects varying across different hours. The intercept and walk ratio were modeled as random parameters, with the walk ratio exhibiting significant temporal variations in its impact on hourly pedestrian crossing demand.

Population (in thousands), walk ratio, the number of lanes at the mid-block location, and the total sidewalk width (in both directions) were found to have positive correlations with crossing demand. Conversely, speed limit displayed negative associations with the crossing demand. The analysis also revealed that mid-block locations with office buildings on one side and residential areas on the opposite side tend to generate lower pedestrian crossing demand. Figure 14 visually confirms this trend, with the office-residential interaction exhibiting lower hourly crossing demand than other types of land-use interaction.

Table 5. Parameters of the Hierarchical Negative Binomial Model

Variables	**Fixed Effects**		**Temporal Random Effects**
	Coeff.	**Std. Error**	**Standard Deviation**
Intercept	0.75	0.45	0.26
Population in thousands	0.08	0.02	-
Walk ratio of commuting trips	3.55	2.05	2.78
Speed limit (mph)	-0.05	0.01	-
Number of lanes at the mid-block location	0.15	0.04	-
Width of the sidewalk in both directions (ft)	0.07	0.02	-
Office-Residential (Yes = 1, No = 0)	-1.57	0.47	-

Notes: Coeff. denotes the regression coefficient, and Std. Error means the standard error.

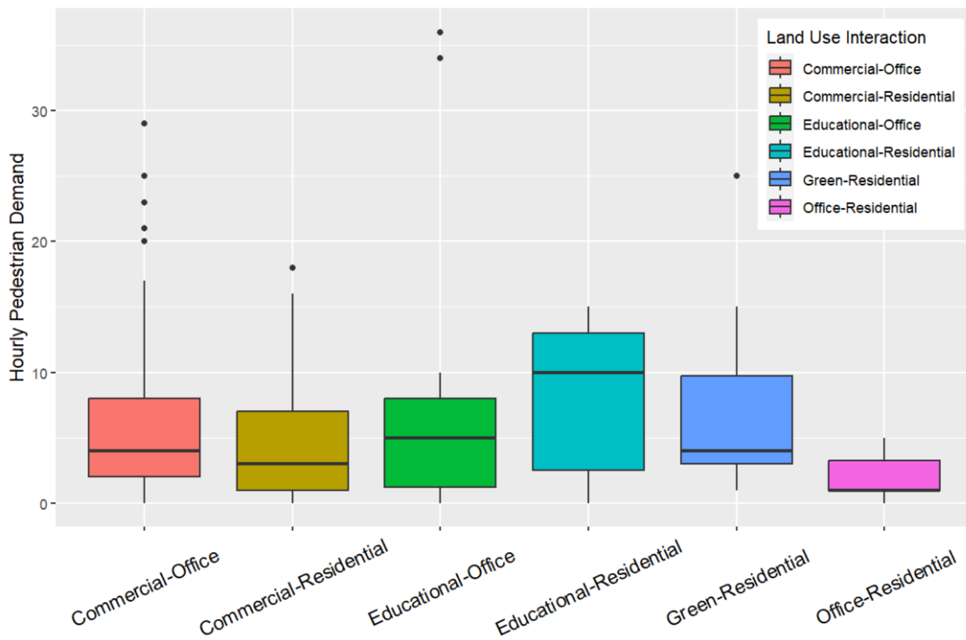


Figure 14. Impacts of Land Use Interactions

Develop Crossing Choice Modes

Model Development

The researchers developed four different SEMs to estimate pedestrian crossing choices: the ungrouped SEM, multigroup SEM with equal thresholds, multigroup SEM with equal regression, and unconstrained multigroup SEM. Table 6 details the performance metrics of these crossing choice models. The null hypothesis of a chi-square test is that the proposed model can fit the data, so insignificant results are desired. However, the chi-square tests always tend to be statistically significant for models with large sample sizes.[17] The root mean square error of approximation (RMSEA) ranges from 0 to 1, with a smaller value indicating a better fit.[17] Tucker-Lewis index (TLI) is less affected by sample size and a larger TLI indicates a better fit to the data.[103] Considering the great number of samples used for model development, the significant results of chi-square tests can be ignored. The multigroup SEM with equal regression yielded the best performance by presenting the lowest RMSEA and the highest TLI. The multigroup SEM with equal regression was chosen for further analysis.

Table 6. Performance Metrics of the Crossing Choice Models

Metrics	**Ungrouped SEM**	**Multigroup SEMs by Daytime and Nighttime**		
		Equal Thresholds	**Equal Regression**	**Unconstrained**
Chi-square	3252.06	3264.36	3196.45	3300.36
Degree of freedom	93	193	199	186
P-value	0.00	0.00	0.00	0.00
RMSEA	0.09	0.09	**0.08**	0.09
TLI	0.68	0.70	**0.72**	0.69

Note: SEM means structural equation model

Figure 15 and Figure 16 show the path diagrams of mid-block crossing at daytime and nighttime, respectively. As described in the methods, this study used five questions to measure safety awareness and four questions to assess delay tolerance (questions detailed in Appendix B). All nine questions used a five-point Likert scale, with higher values indicating greater safety awareness and delay tolerance. Table 7 presents the modeling results of the multigroup SEM with equal regression. As expected by our initial proposition, the coefficients for all questions (Q1-Q9) in the measurement model were positive, as shown in Table 7.

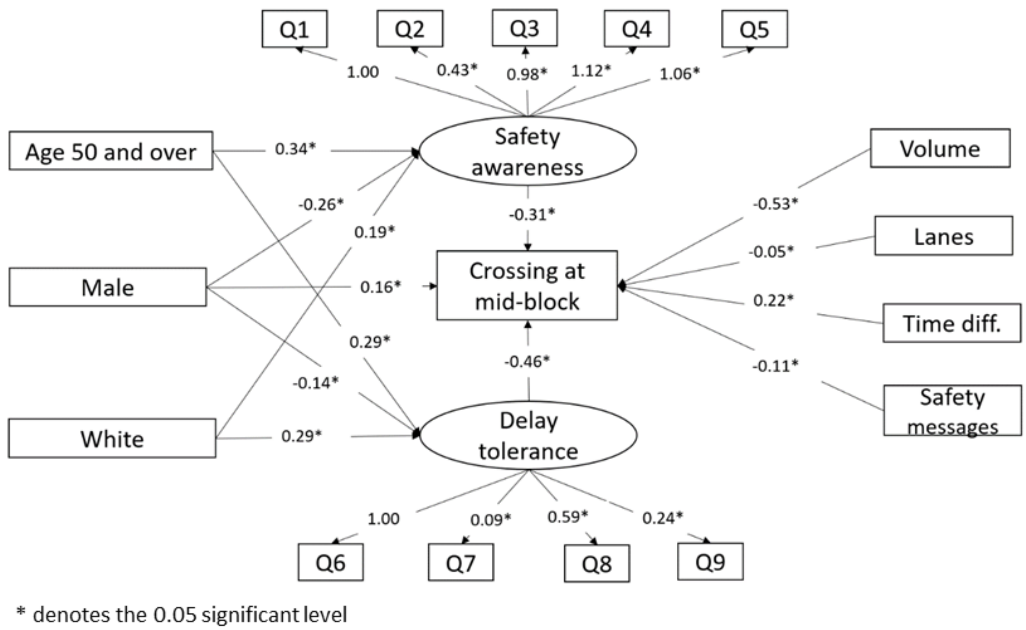


Figure 15. Path Diagram of Mid-block Crossing at Daytime

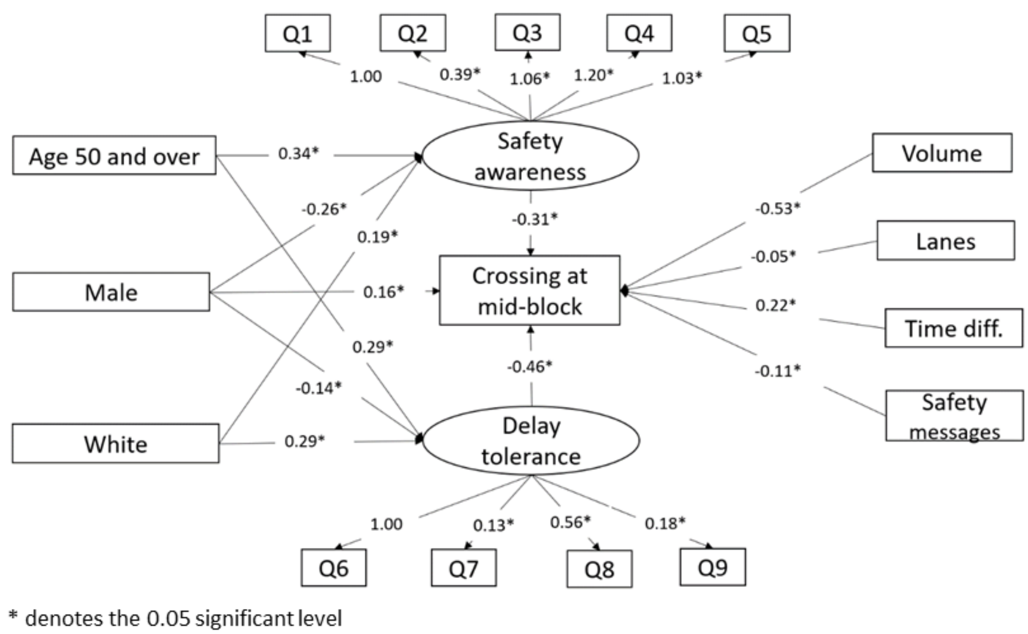


Figure 16. Path Diagram of Mid-block Crossing at Nighttime

Table 7. Modeling Results of the Multigroup SEM with Equal Regression

		Daytime		Nighttime	
		Estimate	Std. Error	Estimate	Std. Error
Measurement Model					
Safety awareness					
Q1 [a]		1.00	-	1.00	-
Q2		0.43	0.03	0.39	0.03
Q3		0.98	0.05	1.06	0.05
Q4		1.12	0.05	1.20	0.06
Q5		1.06	0.06	1.03	0.06
Delay tolerance					
Q6		1.00	-	1.00	-
Q7		0.09	0.03	0.13	0.03
Q8		0.59	0.06	0.56	0.06
Q9		0.24	0.04	0.18	0.04
Structural Model					
Safety awareness	Age 50 and over (No = 0, Yes = 1)	0.34	0.03	0.34	0.03
	Male (No = 0, Yes = 1)	-0.26	0.02	-0.26	0.02
	White (No = 0, Yes = 1)	0.19	0.02	0.19	0.02
Delay tolerance	Age 50 and over (No = 0, Yes = 1)	0.29	0.04	0.29	0.04
	Male (No = 0, Yes = 1)	-0.14	0.04	-0.14	0.04
	White (No = 0, Yes = 1)	0.29	0.04	0.29	0.04
Crossing at the mid-block location	Safety awareness	-0.31	0.04	-0.31	0.04
	Delay tolerance	-0.46	0.04	-0.46	0.04
	Safety messages	-0.11	0.05	-0.11	0.05
	Number of vehicles per hour per lane (in thousands)	-0.53	0.14	-0.53	0.14
	Number of lanes in both directions	-0.05	0.01	-0.05	0.01
	Travel time difference (min) [b]	0.22	0.04	0.22	0.04
	Male (No = 0, Yes = 1)	0.16	0.05	0.16	0.05
Threshold		0.65	0.16	0.67	0.16

Notes: [a] The definitions of Q1-Q9 are detailed in Table 3. [b] Travel time difference is the travel time of crossing at the intersection crosswalk minus the travel time of crossing at the mid-block location.

For the structural model part, pedestrian characteristics such as age, gender, and race were found to significantly affect safety awareness and delay tolerance. Older participants (aged 50 and above) demonstrated higher levels of both safety awareness and delay tolerance. Male participants exhibited a tendency towards lower safety awareness and delay tolerance compared to females. White participants tended to score higher on both the safety awareness and delay tolerance measures.

The analysis identified several factors influencing the likelihood of pedestrians choosing mid-block crossings during both daytime and nighttime. Higher safety awareness and delay tolerance were associated with a lower probability of mid-block crossing. This suggests that pedestrians who prioritize safety and are delay tolerant are more likely to use designated crosswalks. The presence of the safety message (presumably encouraging crosswalk use) was also found to decrease the likelihood of mid-block crossing at all times. A higher number of vehicles per hour per lane was negatively associated with mid-block crossing, indicating a deterrent effect of heavier traffic. A larger difference in travel time between the mid-block location and the nearest crosswalk was positively associated with mid-block crossing. This suggests that when the designated crosswalk is significantly farther away, pedestrians are more likely to take the shorter route, even if it's a mid-block crossing. Male participants exhibited a higher tendency to cross at mid-block locations compared to females. Additionally, a higher threshold for nighttime indicated a reduced tendency for pedestrians to cross at mid-block locations during the nighttime period.

Model Validation and Calibration

The crossing choice models were developed using survey data and were validated with the collected field observation data before they are used. This project adopted a grid search approach to find the optimal validation factor. As indicated in Table 8, the optimal validation factor was found to be 0.75. By increasing the crossing choice utility by 0.75, it can minimize the summation of the absolute difference between the weighted average observed mid-block crossing probabilities (P_{day} and P_{night}) and the weighted average estimated mid-block crossing probabilities ($\widehat{P_{day}}$ and $\widehat{P_{night}}$).

Table 8. Grid Search of the Validation Factor

Validation Factor	**0**	**0.20**	**0.40**	**0.60**	**0.70**	**0.75**	**0.80**	**1.00**
$\widehat{P_{day}}$	25%	31%	39%	46%	50%	52%	54%	62%
$\widehat{P_{night}}$	26%	33%	40%	47%	51%	53%	55%	63%
abs($P_{day}-\widehat{P_{day}}$) + abs($P_{night}-\widehat{P_{night}}$)	53%	40%	25%	11%	3%	**1%**	9%	21%

The crossing choice models can optionally undergo calibration to potentially improve the accuracy of estimates for specific locations. This process involves identifying a calibration factor (in addition to the validation factor) that minimizes the discrepancy between observed and predicted crossing probabilities at a particular site. For example, Table 9 shows the results of a grid search for the calibration factor applied to site 24 from the field observations. The analysis identified an optimal calibration factor of 0.35 for this site. This suggests that by increasing the crossing choice utility further by 0.35 (in addition to the validation adjustment of 0.75), it would minimize the difference between the observed pedestrian crossing data and the estimated probabilities for daytime crossings. Calibration was performed exclusively on daytime data, which included observations of 21 crossing pedestrians. This decision was made due to the limited availability of nighttime data, with only one crossing pedestrian observed at that site during that period.

Table 9. Grid Search of the Calibration Factor for Site 24

Calibration Factor	0	0.10	0.20	0.30	0.35	0.40
$\widehat{P_{day}}$	57.5%	61.4%	65.1%	68.7%	70.5%	72.2%
abs($P_{day} - \widehat{P_{day}}$)	13.5%	9.6%	5.9%	2.3%	**0.5**%	1.2%

Identify Countermeasures

As discussed in the methods section, potential countermeasures can be identified based on the outputs of the crossing demand and crossing choice models. Table 10 details the countermeasures suggested according to the pedestrian crossing demand and the probability of mid-block crossings. For reference, the average crossing demand was 3.5 pedestrians per hour based on data from the selected field observation sites in one region of Virginia. Figure 9 provides more details on the distribution of hourly pedestrian crossing demand, illustrating the variability and over-dispersion in the data. The probability of mid-block crossings was about 46% from the field data.

This study's framework recommends countermeasures only when there is a high probability of mid-block crossings. For mid-block locations with high mid-block crossing probabilities but low crossing demand, the researchers suggest implementing countermeasures that encourage safe crossings at nearby intersection crosswalks. Conversely, for mid-block locations with high mid-block crossing probabilities and high crossing demand, the researchers recommend countermeasures that improve the safety of mid-block crossings.

Table 10. Identification of Potential Countermeasures

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Crossing Demand (As a reference, the average crossing demand of the selected sites was 3.5 per hour during the observation period)</td></tr>
<tr><td>Low</td><td>High</td></tr>
<tr><td rowspan="2">Mid-block Crossing (As a reference, the probability of mid-block crossing at the selected sites was 46%)</td><td>Unlikely</td><td>No countermeasures recommended</td><td>No countermeasures recommended</td></tr>
<tr><td>Likely</td><td>Encourage safe crossings at the nearby intersection crosswalk:
Reduce pedestrian delay at the nearest intersections (e.g., provide a pedestrian signal push button, adjust signal timing, etc.)
Locate pedestrian generators (e.g., bus stops) closer to intersections with crosswalks.
Prevent mid-block crossing using physical fencing.
Education and communications (e.g., general pedestrian safety campaigns cautioning against the high risks of mid-block crossing)</td><td>Improve the safety of mid-block crossings:
Improve infrastructure and design (e.g., raised median, road diet, speed calming, enhanced lighting conditions, adding sidewalks, etc.)
Improve control and enforcement (e.g., provide marked high-visibility crosswalks, advanced stop bars, pedestrian hybrid beacon (PHB), rectangular rapid flash beacon (RRFB), pedestrian warning signs, dynamic feedback signs, driver-yielding enforcement, etc.)</td></tr>
</table>

The researchers incorporated the crossing demand and choice models into the PedAct tool to facilitate the countermeasure development. Figure 17 presents the interface of the PedAct tool, which is divided into two main sections: the input section and the output section. The input section allows users to input variables such as demographics, land use context, road geometry, traffic conditions, and control and enforcement. The output section displays pedestrian crossing demand per hour, probability of crossing at mid-block at daytime, and probability of crossing at mid-block at nighttime.

A Tool to Estimate Pedestrian Crossing Demand and Choices			
Site Name:			
	Input		**Output**
Demographics [1]	*Population in thousands*	3.779	*Pedestrian crossing demand per hour (14:00-22:00)*
	Walk ratio [2] *(between 0 and 1)*	0.01	**2**
	Ratio of people aged 50 and over (between 0 and 1)	0.313	
	Ratio of males (between 0 and 1)	0.46	*Probability of crossing at mid-block at daytime*
	Ratio of white race (between 0 and 1)	0.57	**70.4%**
Land use context	*Land use interaction* [3]	Others	
Road geometry	*Total width of sidewalks on both sides (ft)*	8	*Probability of crossing at mid-block at nighttime*
	Number of lanes at the mid-block location	5	**69.8%**
	Presence of median	Yes	
	Distance to the nearest crosswalk (ft)	245.5	
Traffic conditions	*Number of vehicles per hour per lane*	196.5	
Control and enforcement	*Speed limit (mph)*	35	
	Pedestrian signal delay at intersection (s) [4]	53.5	
	Presence of a safety message [5]	No	
Local calibration factor [6]	*Calibration coefficient for crossing choices at the mid-block location*	0.35	
Notes:			
[1] *Demographics in the census tract (Data available at https://censusreporter.org/locate/)*			
[2] *Walk ratio is the proportion of trips choosing walking as a primary commuting mode in the census tract, expressed as a value between*			
[3] *Land use interaction denotes the interactions between dominant land use types (i.e., commercial, residential, educational, office, and*			
[4] *Pedestrian signal delay is half of the red interval for pedestrians at a signalized intersection and zero for an unsignalized intersection.*			
[5] *Safety message denotes general pedestrian safety campaigns cautions against the high risk of the mid-block crossing*			
[6] *Local calibration factor is used to calibrate the model to estimate crossing choices more accurately when local data is available*			

Figure 17. Interface of the PedAct Tool with Inputs and Outputs of the Site 24

Take Site 24 as an example to illustrate the use of the PedAct tool for countermeasure identification. As shown in Figure 17, the pedestrian crossing demand is estimated to be 2 per hour, while the daytime and nighttime probabilities of crossing at mid-block are estimated to be 70.4% and 69.8%, respectively. The estimated crossing demand is much lower than the average 3.5 per hour, while the mid-block crossing probabilities are much higher than the baseline 46%. This site is categorized as high mid-block crossing probability and low crossing demand, and thus, countermeasures that encourage safe crossings at nearby intersection locations should be recommended.

According to Table 10, a series of countermeasures are identified for Site 24, including reducing the traffic signal delay (e.g., by providing a pedestrian push button), reducing the distance to the nearest crosswalk (e.g., relocating trip generators such as bus stops), and presenting a safety message (e.g., raising the awareness on the high risk of mid-block crossing via pedestrian safety campaigns). To support decision-making regarding countermeasures, the PedAct tool can be used again to estimate the mid-block crossing probabilities associated with various sets of countermeasures by changing the input variables. Table 11 shows the proposed countermeasures and their estimated effectiveness in reducing mid-bock crossing probabilities. By combining a series of countermeasures, Countermeasure 6 is expected to reduce the daytime mid-block crossing probability to 48% from the baseline of 71%.

Table 11. Potential Countermeasures and Their Effectiveness in Reducing Mid-block Crossing Probabilities

Scenarios	$\widehat{P_{\text{daytime}}}$ (Estimated probability of mid-block crossing at daytime)
No countermeasure	71%
Countermeasure 1 (-20 s traffic signal delay)	68%
Countermeasure 2 (-40 s traffic signal delay)	65%
Countermeasure 3 (-100 ft distance to the nearest crosswalk)	64%
Countermeasure 4 (-200 ft distance to the nearest crosswalk)	58%
Countermeasure 5 (presence of a safety message)	66%
Countermeasure 6 (-40 s traffic signal delay, -200 ft distance to the nearest crosswalk, and presence of a safety message)	48%

DISCUSSION

This study contributes to the literature by developing scientifically rigorous pedestrian crossing demand and choice models using field observation and survey data. It provides insights into the relationship between a wide range of contributing factors such as demographics, land use, road geometry, traffic conditions, traffic control and enforcement, and pedestrian crossing behavior. The PedAct tool developed has the potential to facilitate decision-making for countermeasures development. However, it should also be noted that resource constraints limited the study's scope. This section discusses these limitations and cautions against overgeneralizing the results.

- The pedestrian crossing demand model developed in this study is primarily based on field observation data from the Hampton Roads area, rather than the entire state of Virginia. Pedestrian crossing demand may exhibit significant spatial heterogeneity across different regions of Virginia. Therefore, the pedestrian crossing demand model may require recalibration with additional field observations from various regions throughout Virginia to adequately account for this spatial heterogeneity.

- Pedestrian field data for this study were collected between 14:00 and 22:00. Caution is advised when generalizing the findings to other time windows.

- The pedestrian crossing choice models developed in this study do not fully account for the spatial heterogeneity of choice preferences. Although the survey included residents from across Virginia, the limited number of participants from certain cities or counties might restrict the ability to make reliable inferences at the local level. It is suggested to recalibrate the crossing choice models when local data are available.

- The survey in this study did not include participants under 18 due to IRB restrictions and had very few seniors over 65. As a result, the applicability of the crossing choice models across different age groups needs further validation.

- Adjustments are necessary before applying the crossing choice models developed from the survey data to real-world scenarios. In this study, only the intercept of the utility function was adjusted. Future research can explore other alternative methods to enhance the model's accuracy and applicability.

- The PedAct tool effectively evaluates the impact of potential countermeasures on pedestrian exposure to crash risks provided their impact can be measured using input variables in the tool. However, the feasibility of these countermeasures depends on the unique context of each site. For example, reducing pedestrian signal delay may necessitate reconfiguring signal timing, which could increase overall intersection delay. Engineering judgment is essential to making informed decisions when using the tool for countermeasure development.

Despite these limitations, this study has established a framework to integrate quantitative methods for more informed decision-making to enhance pedestrian safety. The crossing demand and choice models, along with the PedAct tool, can be continuously improved with additional data collected from various regions and population groups.

CONCLUSIONS

- *Pedestrian crossing demand and crossing choices are affected by a wide range of contributing factors, including demographics, land use, road geometry, traffic conditions, traffic control, and enforcement.* More specifically, factors such as population, walk ratio of commuting trips, speed limit, number of lanes, sidewalk width, and land use interaction were found to affect crossing demand. Meanwhile, the presence of safety messages, traffic volume, number of lanes, travel time saved by mid-block crossing, and gender were found to influence crossing choices.

- *Human factors such as safety awareness and delay tolerance are critical in explaining crossing choices. These factors can vary considerably across different demographics, with pedestrian characteristics like age and gender playing a key role.*

- *The hierarchical negative binomial (HNB) model developed effectively accounts for the temporal variations in pedestrian crossing demand.*

- *The multigroup SEM developed in this study demonstrates its advantages in accounting for preference heterogeneity across different times of the day. It also effectively measures human factors and models the interrelationships among human factors, crossing choices, built environments, travel time differences, and pedestrian characteristics.*

- *The crossing demand and choice models developed in this study facilitate the identification of countermeasures and enable the evaluation of their effectiveness in changing pedestrian crossing behaviors. The feasibility of implementing these countermeasures is contingent upon the unique context of each site, necessitating careful engineering judgment to make well-informed decisions.*

RECOMMENDATION

1. *The Virginia Transportation Research Council (VTRC) should conduct a pilot study to integrate the crossing demand and choice models into the process of pedestrian safety management using the PedAct tool.* This pilot study will be instrumental in demonstrating the usability and effectiveness of these quantitative methods in supporting real-world decision-making such as identification of locations with pedestrians exposed to high risk and the

development of countermeasures. Feedback from the pilot may identify potential improvements to these models and how to best utilize them to make informed decisions to enhance pedestrian safety.

IMPLEMENTATION AND BENEFITS

The researchers and the Technical Review Panel (TRP) for the project (listed in the Acknowledgments) collaborated to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here. This pilot project would be a follow-up research project.

Implementation

The research team has developed an Excel-based tool, PedAct, to facilitate the use of the crossing demand and choice models for real-world decision making. Excel was chosen for the user interface due to its availability on VDOT computers and ease of use. The introduction and guide for using the tool can be found in Appendix D.

The next step is for the project champion (TOD division administrator or his designated staff), ODU, and VTRC to develop a research project needs statement (RNS) for consideration by the VTRC Traffic and Safety Research Advisory Committee, TASRAC in fall 2024. The RNS should include a more detailed description of the proposed research project. VDOT staff and local stakeholders will be consulted to define the study area and scope. It is anticipated that the PedAct tool developed and the PSAP map will be used to select mid-block locations for the proposed pilot study. Additional field data would be collected to validate the accuracy of the tool’s outputs and calibrate it for specific districts. Targeted countermeasures to enhance pedestrian safety will be identified for these mid-block locations based on the tool’s outputs and expert recommendations. The effectiveness of these countermeasures will be assessed using the tool. Pilot study findings and user feedback would be incorporated to refine the PedAct tool for optimal performance. Following the successful validation of the tool's effectiveness, the research team will develop a comprehensive user guide and conduct a webinar for VDOT staff. This webinar will cover the application of the tool, best practices, and case studies to ensure effective usage.

Additionally, a second RNS that focuses on countermeasures for mid-block crossing may be submitted since it may be very useful to have specific guidance and information on countermeasures to consider for implementation.

Benefits

VDOT places significant emphasis on improving pedestrian safety, and further developing the PedAct tool to ensure it is broadly applicable across Virginia will advance the goal of improving pedestrian safety. The PedAct tool has the potential to enhance VDOT's decision-making process in pedestrian safety management, ultimately reducing pedestrian crashes. Specifically, the PedAct tool offers the following benefits:

- Help identify mid-block locations with high crossing probabilities and high crossing demand. Given the sparsity of pedestrian crash data, crash-based methods alone may not be sufficient to identify high-risk locations for pedestrians. The tool provides valuable estimates of pedestrian exposure to safety risks, complementing crash data to more accurately pinpoint high-risk mid-block locations.
- Assist in developing countermeasures to enhance pedestrian safety. The tool provides quantitative indicators that complement engineering judgment in identifying appropriate countermeasures, such as encouraging safe crossings at nearby locations or enhancing the safety of mid-block crossings. Table 10 lists countermeasures to be considered based on estimated crossing demand and mid-block crossing probabilities from the tool.
- Aid in estimating the effectiveness of certain countermeasures. The tool offers insights into how specific countermeasures may change pedestrian behaviors. For instance, it can evaluate how the presence of a closer crosswalk might reduce the probability of mid-block crossings. This information is crucial for assessing the potential benefits of countermeasures and prioritizing their implementation.

ACKNOWLEDGEMENTS

The authors highly appreciate the contributions and feedback received from all who served on the technical review panel: Mark Cole (VDOT Traffic Operations Division), Michael Fontaine (VTRC), Benjamin Cottrell (VTRC), Peter Ohlms (VTRC), Gil Chlewicki (VDOT Northern Virginia District), Mike Sawyer (City of Richmond), and Matt Bond (VDOT Staunton District).

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APPENDIX A: FIELD DATA COLLECTION FORM

Site identifier: Date: Weather condition: Investigator:

Time interval between consecutive onsets of green time for crossing: ____s Green interval for crossing: _____s Pedestrian push-button available: □ yes □ no

Pedestrian push-button affecting crossing time: □ yes □ no Left turn protection available: □ yes □ no

Lighting at the intersection: □ yes □ no Lighting at the midblock: □ yes □ no

Ped ID	**Time** (15-min increments, e.g., 16:15)	**Age** group (0: <18, 1: 18- 65, 2: >65, 3: unsure)	**Gender** (0: male, 1: female, 2: unsure or other)	**Walking in a group** (0: no, 1: yes)	**Crossing occurrence** (0: no, 1: yes)	**Crossing location** (0: intersection, 1: mid-block)	**Small gap for crossing/near-miss** (0: no, 1: yes)	**Driver yield** (0: no, 1: yes)	**Crossing strategy** (0: single stage, 1: two or more stages)	**Note** (unusual events such as homeless, police car, failure to cross)

APPENDIX B: SURVEY QUESTIONNAIRE

Introduction

Over 6,500 pedestrians were killed in traffic collisions in the United States in 2020. The Virginia Department of Transportation (VDOT) has asked researchers at Old Dominion University (ODU) to investigate pedestrian crossing behaviors and identify ways to improve pedestrian safety. This survey aims to collect information about your own behavior as a pedestrian. This survey should take about **10-15 minutes** to complete.

The results of this study may be used in reports, presentations, and publications, but the researchers will not identify you in any way. If you are not satisfied with the manner in which this study is being conducted, you may report (anonymously if you so choose) any concerns to Dr. Kun Xie, at kxie@odu.edu, or Dr. Tancy Vandecar-Burdin, Chair of the Institutional Review Board at tvandeca@odu.edu or 757-683-3802.

Informed Consent

Exclusionary Criteria

All participants in this survey must be at least 18 years of age and live in Virginia.

Risk and Benefit

Your responses will be anonymous, and no personal identifier will be collected in the survey to protect your confidentiality. You may receive a gift card by participating the survey.

Confidentiality

The researchers will take reasonable steps to keep your information confidential. No personally identifiable information will be collected in the survey. All information collected will be securely stored in ODU computers behind firewalls and accessible with monitored authentication.

Withdrawal Privilege

Your participation is voluntary, and you may choose to withdraw from the study at any time.

Please click "**Next**" if you are aware of the information above and consent to participate and continue with the survey. Thank you for your participation

Safety Message (Presented to randomly selected participants before the crossing scenarios): About **70%** of pedestrian fatalities involve mid-block crossings in Virginia.

Part 1. Pedestrian Crossing Choices

You will be presented with a series of images representing streets with different configurations and speed limits. Each image shows your points of origin and destination as someone crossing the street, whether you are crossing alone or in a group, the distance to the nearest crosswalk, and expected travel times for two crossing options (where "ft" means feet and "s" means seconds). You will be asked to choose between two options for each image. Choose the option that best represents how you think you would cross the street. You will then be asked to select reasons for your choice.

Table B1. Characteristics of Crossing Scenarios Selected

Scenario ID	Presence of Median	Distance to the Nearest Crosswalk	Whether in a Group	Lighting Condition	Control Type of the Nearest Crosswalk	Traffic Volume per Hour per Lane	Number of Lanes	Speed Limit (mph)
1	No	240 ft	No	Daytime	Signalized (waiting time: 30 sec)	100 (Low)	2	25 mph
2	Yes	160 ft	Yes	Nighttime	Signalized (waiting time: 60 sec)	1,000 (High)	2	25 mph
3	Yes	160 ft	No	Daytime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	100 (Low)	4	25 mph
4	No	80 ft	Yes	Daytime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	500 (Medium)	4	25 mph
5	Yes	80 ft	Yes	Nighttime	Signalized (waiting time: 30 sec)	500 (Medium)	6	25 mph
6	No	240 ft	No	Nighttime	Signalized (waiting time: 60 sec)	1,000 (High)	6	25 mph
7	Yes	240 ft	No	Nighttime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	500 (Medium)	2	35 mph
8	No	160 ft	Yes	Daytime	Signalized (waiting time: 60 sec)	500 (Medium)	2	35 mph
9	No	160 ft	No	Nighttime	Signalized (waiting time: 30 sec)	500 (Medium)	4	35 mph
10	Yes	80 ft	No	Nighttime	Signalized (waiting time: 60 sec)	1,000 (High)	4	35 mph
11	Yes	240 ft	Yes	Daytime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	100 (Low)	6	35 mph
12	No	80 ft	No	Daytime	Signalized (waiting time: 60 sec)	100 (Low)	6	35 mph
13	No	160 ft	Yes	Daytime	Signalized (waiting time: 30 sec)	1,000 (High)	6	35 mph
14	Yes	80 ft	Yes	Nighttime	Signalized (waiting time: 30 sec)	100 (Low)	2	45 mph
15	No	80 ft	No	Daytime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	1,000 (High)	2	45 mph
16	No	240 ft	Yes	Nighttime	Signalized (waiting time: 60 sec)	100 (Low)	4	45 mph
17	Yes	240 ft	Yes	Daytime	Signalized (waiting time: 30 sec)	1,000 (High)	4	45 mph
18	No	160 ft	Yes	Nighttime	Uncontrolled or Stop/Yield-controlled (no extra waiting time)	100 (Low)	6	45 mph
19	Yes	160 ft	No	Daytime	Signalized (waiting time: 60 sec)	500 (Medium)	6	45 mph

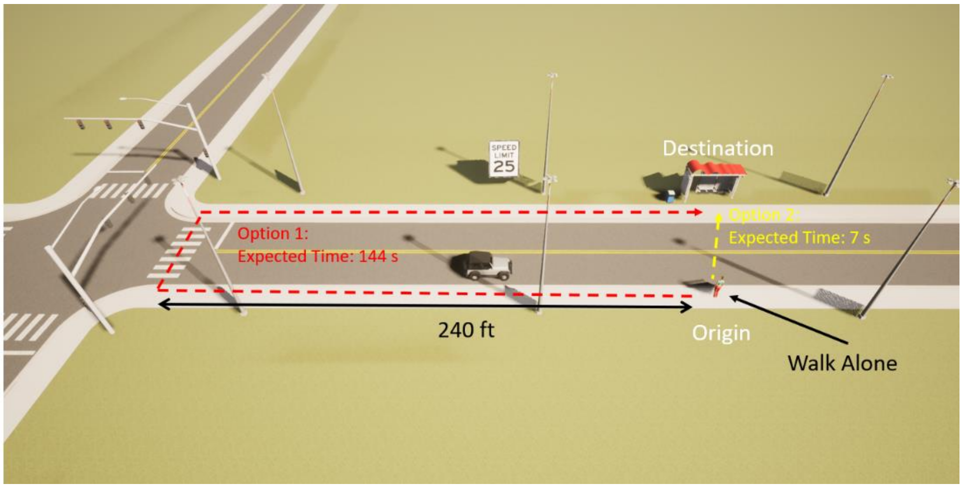


Figure B1. Visualization of Scenario 1

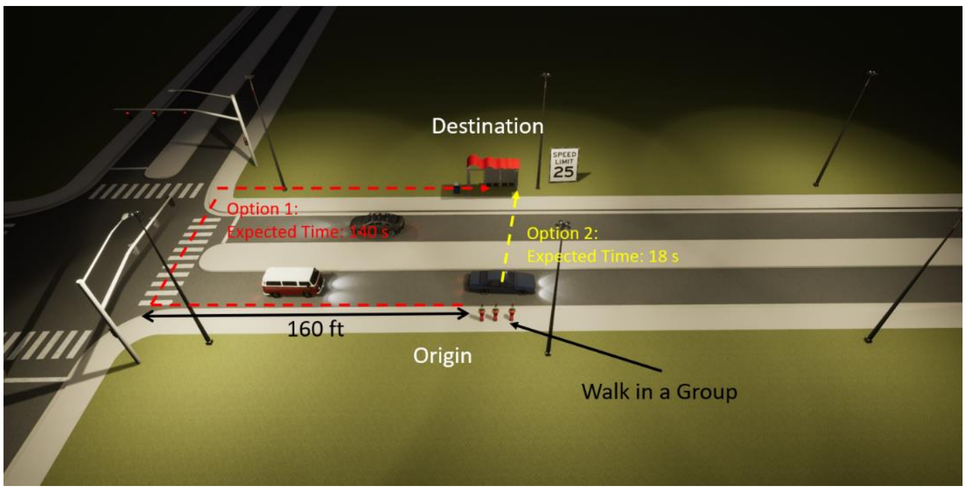


Figure B2. Visualization of Scenario 2

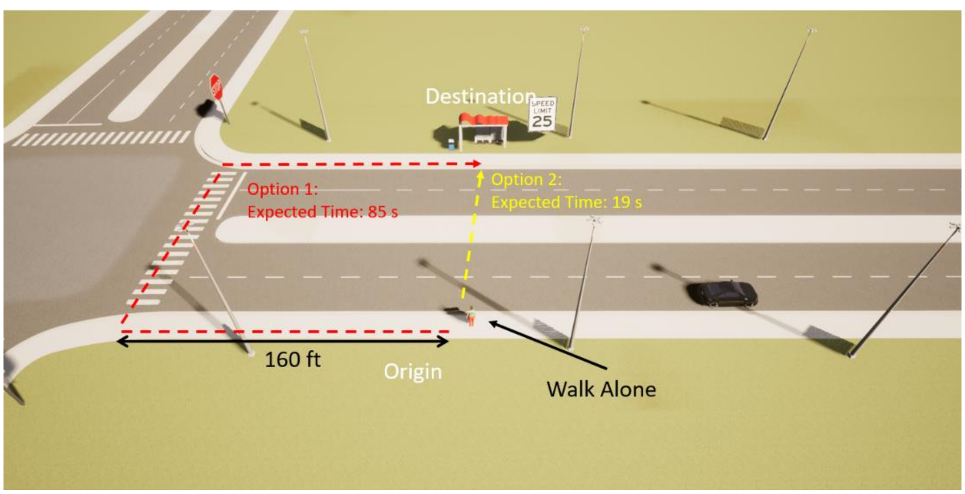


Figure B3. Visualization of Scenario 3

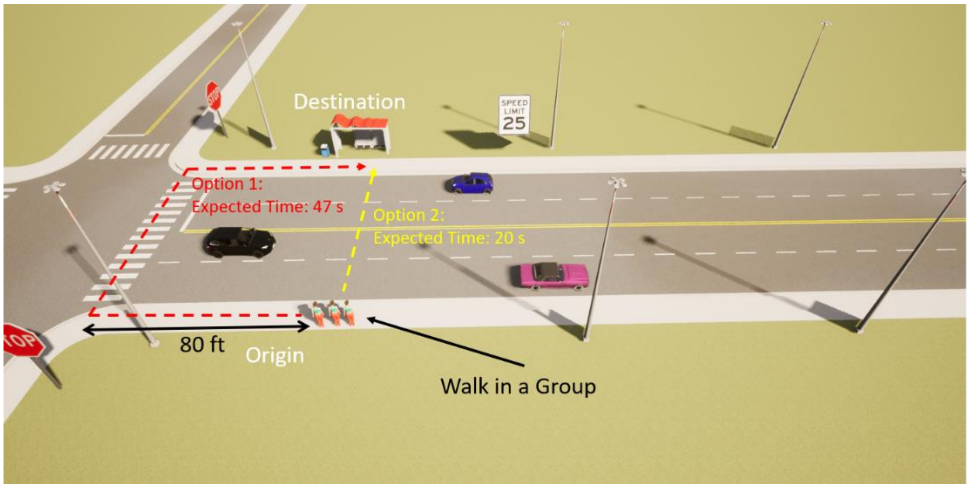


Figure B4. Visualization of Scenario 4

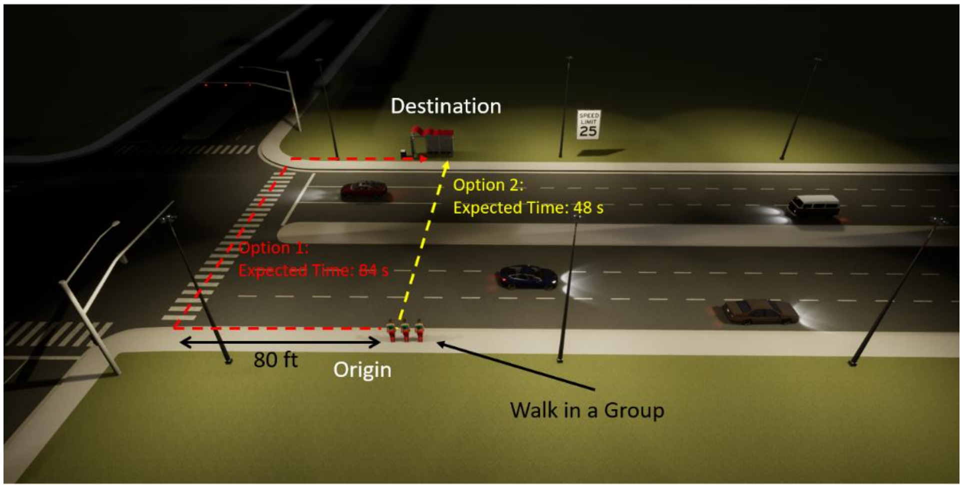


Figure B5. Visualization of Scenario 5

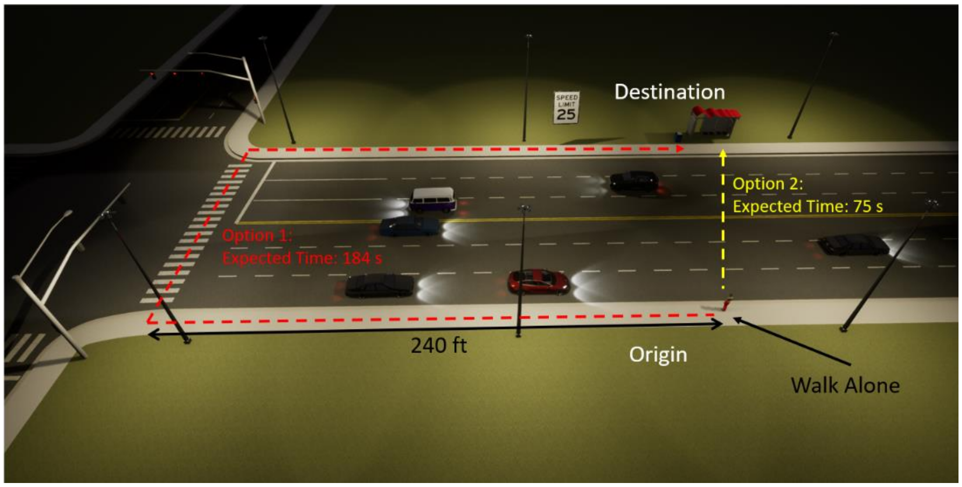


Figure B6. Visualization of Scenario 6

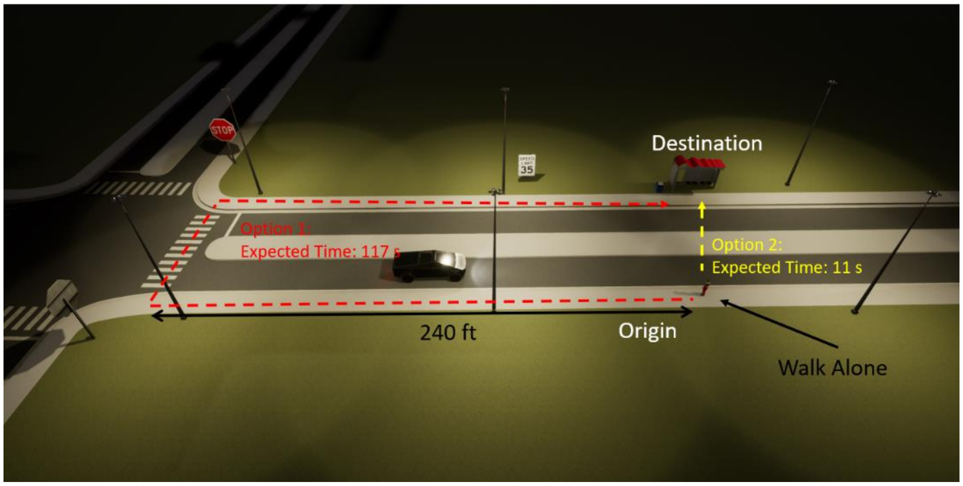


Figure B7. Visualization of Scenario 7

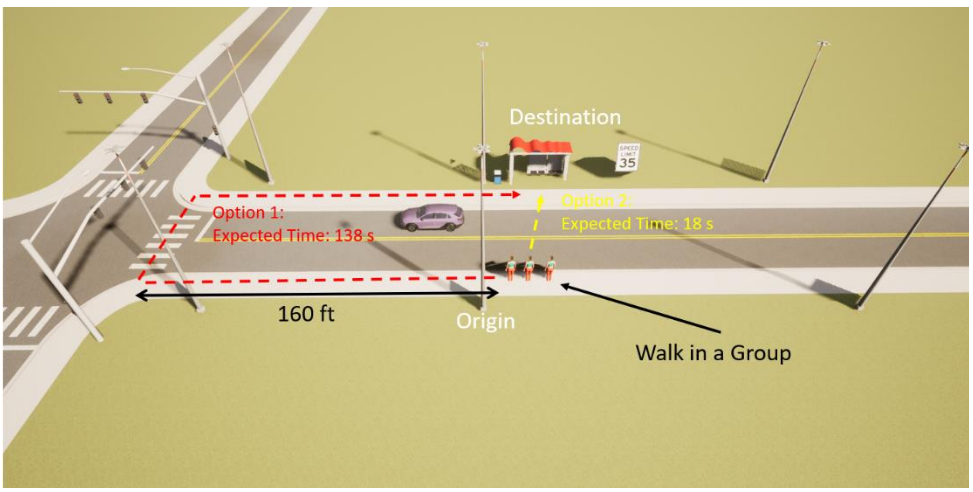


Figure B8. Visualization of Scenario 8

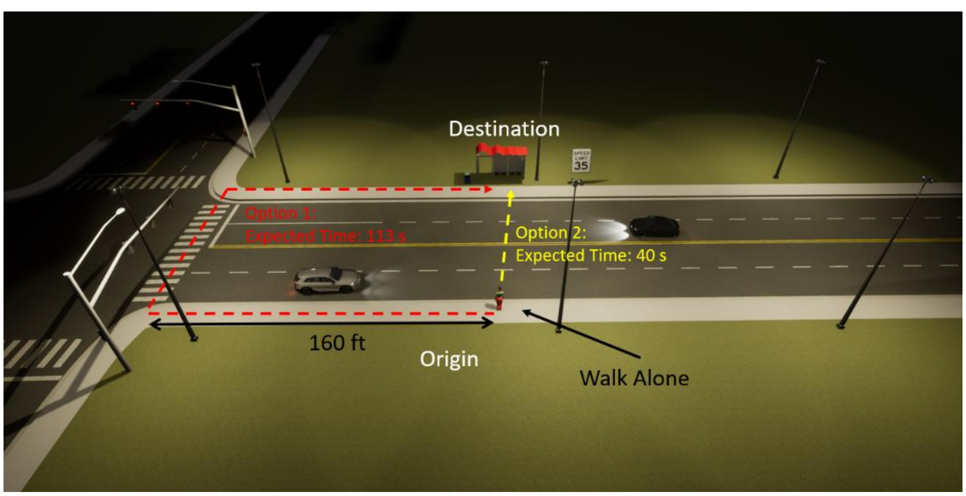


Figure B9. Visualization of Scenario 9

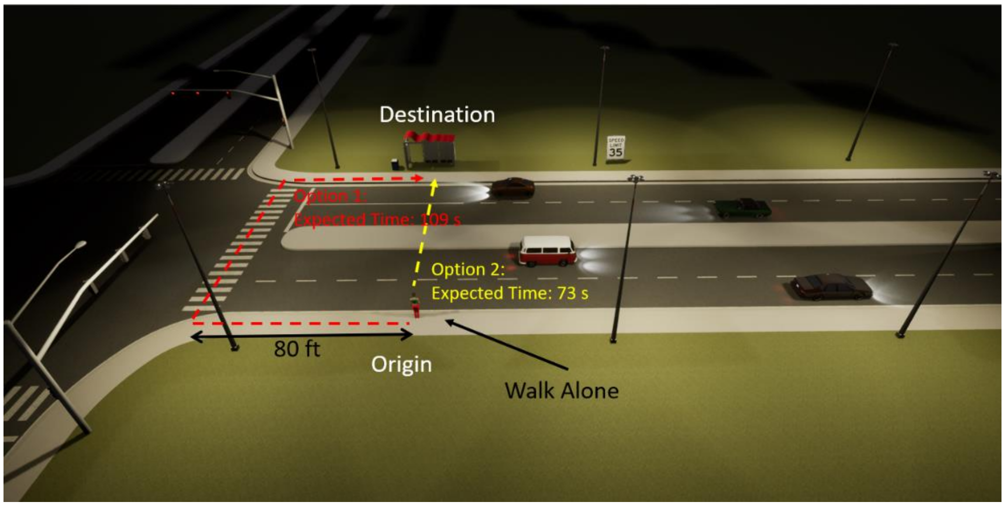


Figure B10. Visualization of Scenario 10

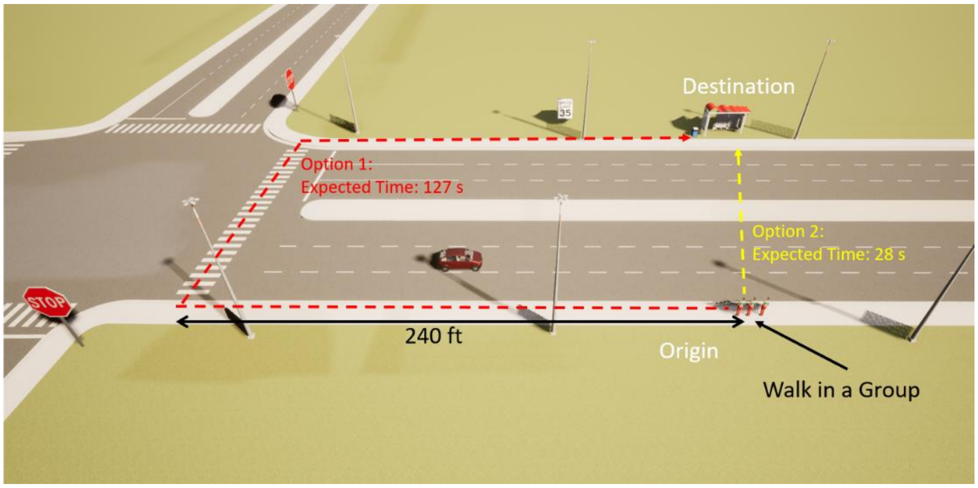


Figure B11. Visualization of Scenario 11

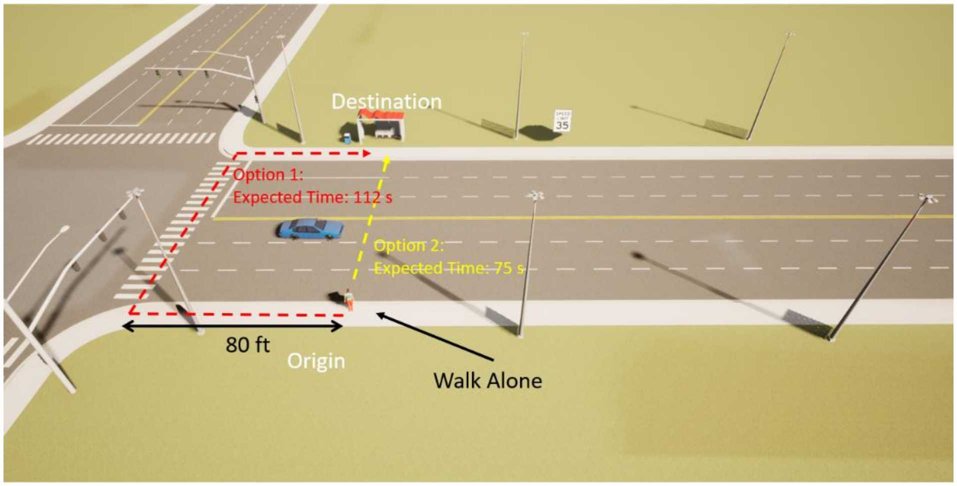


Figure B12. Visualization of Scenario 12

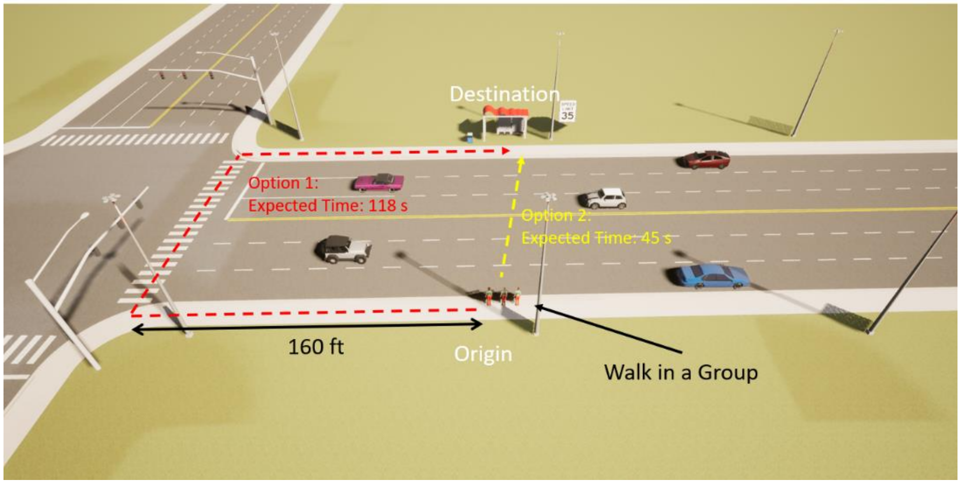


Figure B13. Visualization of Scenario 13

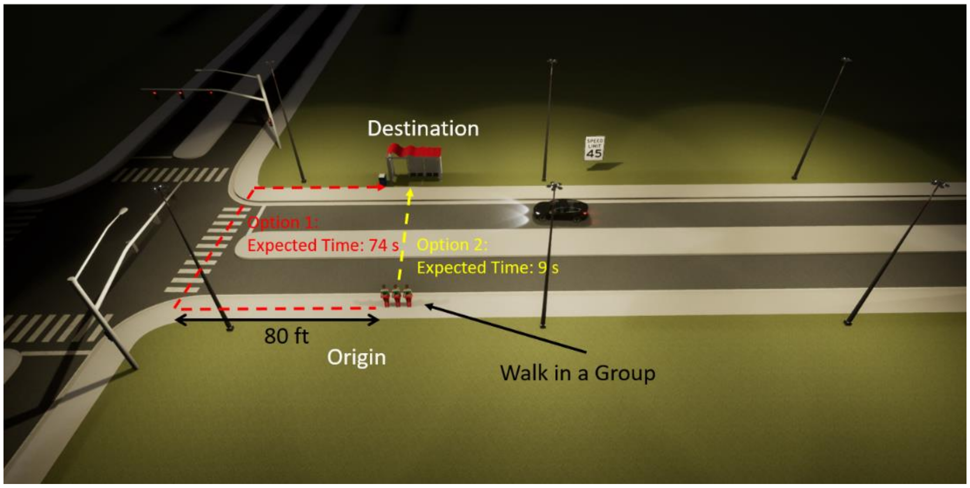


Figure B14. Visualization of Scenario 14

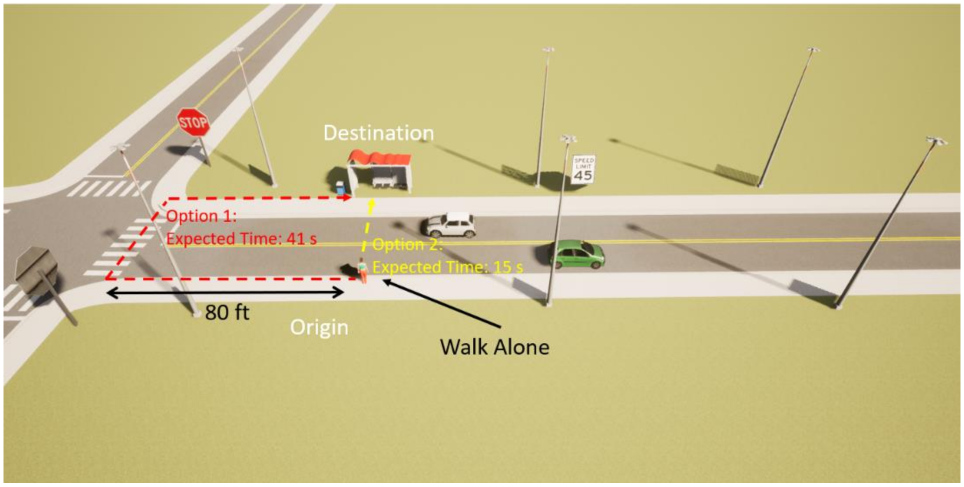


Figure B15. Visualization of Scenario 15

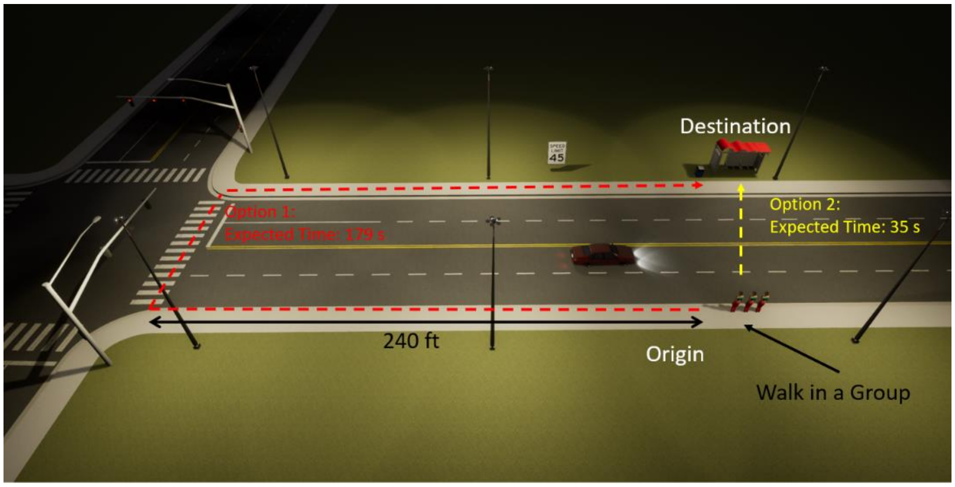


Figure B16. Visualization of Scenario 16

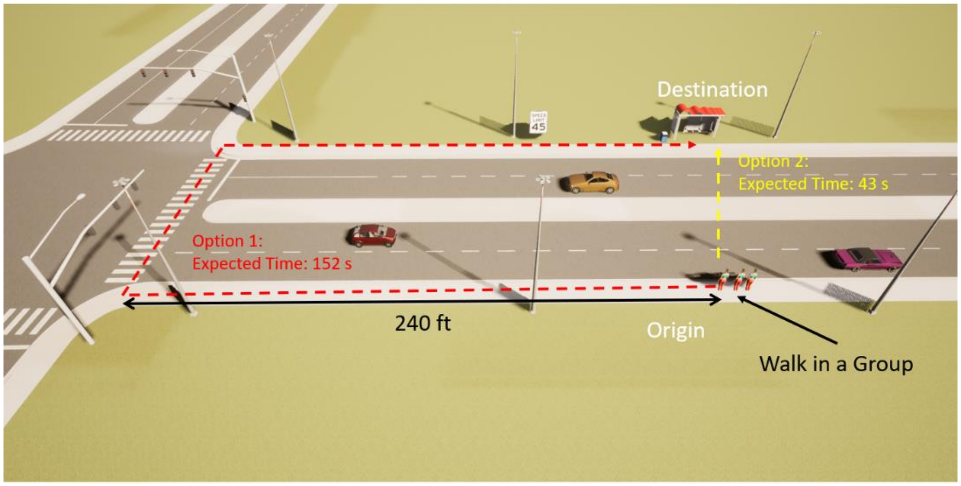


Figure B17. Visualization of Scenario 17

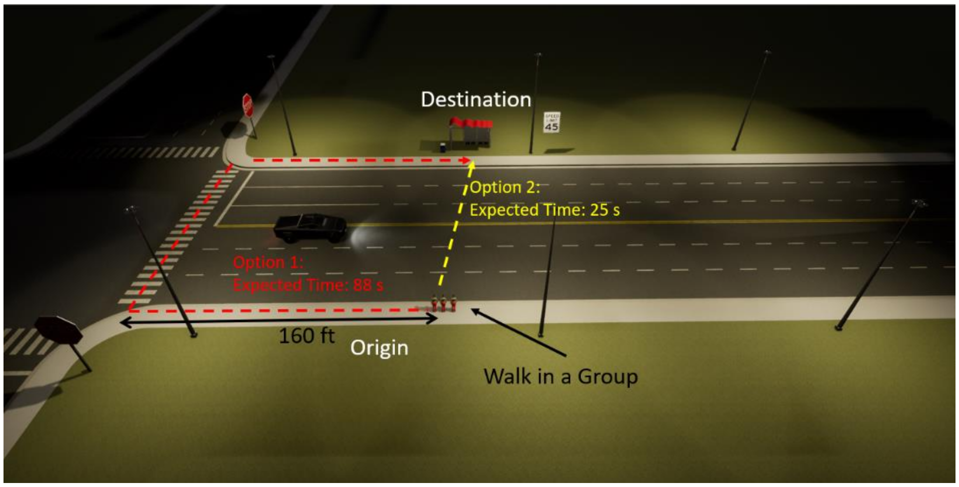


Figure B18. Visualization of Scenario 18

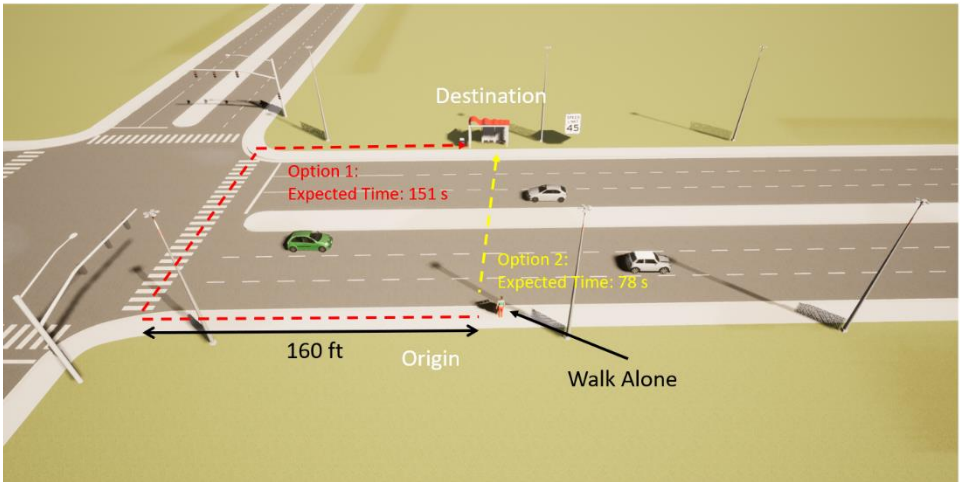


Figure B19. Visualization of Scenario 19

Reasons for Crossing at the Intersection Crosswalk (present to participants who select Option 1 for crossing in each scenario)

- ❑ **Enhanced safety:** Crossing at a marked crosswalk significantly reduces the crash risk as I have the right-of-way and drivers are better aware of my presence.
- ❑ **Responsible behavior:** Crossing at a designated crosswalk is a responsible behavior that shows respect for traffic laws.
- ❑ **Health benefits:** Walking for a longer distance to reach a marked crosswalk can be a great way to incorporate exercise into my daily routine.
- ❑ **Better accessibility:** Curb ramps at an intersection make crossings more accessible.
- ❑ **Others:** ________________________ (please explain other reasons in words).

Reasons for Crossing at the Mid-block (present to participants who select Option 2 for crossing in each scenario)

- ❑ **Shorter time:** Crossing at the mid-block can save time
- ❑ **Shorter distance:** Crossing at the mid-block can reduce the walking distance
- ❑ **Certainty:** The time needed to cross at the mid-block is more predictable, while waiting time to cross at the intersection can be uncertain.
- ❑ **Perceived safety:** I only need to monitor traffic from two directions, as opposed to dealing with traffic from multiple directions at an intersection crosswalk.
- ❑ **Others:** ________________________ (please explain other reasons in words).

Part 2. Human Factors

<u>Safety awareness assessment:</u>

1. How likely is it that you would cross a 6-lane street without a marked crosswalk and without a median?
   - 1-extremely unlikely • 2- unlikely • 3-neutral • 4-likely • 5-extremely likely

2. How often do you follow the signs and signals when crossing the street?
   - 1-never • 2-rarely • 3-sometimes • 4-often • 5-always

3. How often do you use your cell phone while walking across the street?
   - 1-never • 2-rarely • 3-sometimes • 4-often • 5-always

4. How often do you walk in the roadway alongside traffic even when sidewalks are available?
   - 1-never • 2-rarely • 3-sometimes • 4-often • 5-always

5. How often do you cross a street without actively looking for cars as you cross?
   - 1-never • 2-rarely • 3-sometimes • 4-often • 5-always

<u>Delay tolerance assessment:</u>

6. At a traffic light, how likely is it that you would cross a street when no traffic is coming and the solid "Don't Walk" or red light is on for pedestrians?
   - 1-extremely unlikely • 2- unlikely • 3-neutral • 4-likely • 5-extremely likely

7. At crossings where a pedestrian button is available, how likely is it that you would press it?
• 1-extremely unlikely • 2-unlikely • 3-neutral • 4-likely • 5-extremely likely

8. How likely is it that you would run along a marked crosswalk during a WALK phase if you are in a hurry?
• 1-extremely unlikely • 2- unlikely • 3-neutral • 4-likely • 5-extremely likely

9. How likely is it that you would pay $5 for a shuttle bus to reduce travel time by 20 minutes?
• 1-extremely unlikely • 2- unlikely • 3-neutral • 4-likely • 5-extremely likely

Part 3. Pedestrian Characteristics

10. What is your age: • 18-33 • 34-49 • 50-65 • over 65

11. What is your gender: • Female • Male • Transgender • I use a different term: ______

12. What is your race:
• White

• Black or African American

- American Indian or Alaska Native
- Asian
- Native Hawaiian or Other Pacific Islander
- Other
- I prefer not to answer

13. Do you have a valid driver’s license? • Yes • No

14. What is your highest level of education?
- Less than high school
- High school graduate/equivalent
- Some college or associate’s degree
- Bachelor’s degree
- Master's degree
- Doctoral Degree
- Other

15. Have you ever been hit by an automobile while walking across the street? • Yes • No

16. How many vehicles are owned by your household? ___________

17. What is your annual income?
- Less than $15,000
- $15,000 - $34,999
- $35,000 - $54,999
- $55,000 - $99,999
- $100,000 - $124,999
- Over $125,000

- I prefer not to answer

18. In what city or county do you live? _______________

APPENDIX C: CHARACTERISTICS OF SELECTED SITES FOR FIELD DATA COLLECTION

Table C1. Characteristics of Selected Sites for Field Data Collection

ID	Route Name	Start	End	City or County	Number of Lanes at Mid-block	Speed Limit (mph)	Presence of Raised Median	Presence of Bus Stop	Total Width of Sidewalk (ft)	Land Use Interaction	VDOT PSAP Corridor
1	Hampton Blvd	Bolling Ave	Exit of Parking Lot # 1	City of Norfolk	6	30	Yes	Yes	10	Education-Office	Yes
2	Hampton Blvd	W Princess Anne Rd	Maury Ave	City of Norfolk	4	30	No	Yes	10	Green space-Residential	Yes
3	E Princess Anne Rd	Marshall Ave	Exit of Booker T. Washington High School	City of Norfolk	5	25	No	Yes	12	Education-Residential	Yes
4	W Little Creek Rd	Ruthven Rd	Nesbitt Dr	City of Norfolk	4	25	No	Yes	12	Office-Residential	Yes
5	E Ocean View Ave	N Beach View St	Exit of Best Western Plus Holiday Sands Inn & Suites	City of Norfolk	5	25	No	No	10	Commercial-Residential	Yes
6	E Ocean View Ave	3rd Bay St	5th Bay St	City of Norfolk	3	25	No	Yes	14	Green space-Residential	Yes
7	Shore Dr	Dunning Rd	Hacienda St	City of Norfolk	5	25	Yes	Yes	10	Commercial-Residential	Yes
8	E Little Greek Rd	Halprin Dr	Wildwood Dr	City of Norfolk	6	25	Yes	Yes	12	Commercial-Office	Yes
9	Azalea Garden Rd	Robin Hood Rd	Beamon Rd	City of Norfolk	2	25	No	Yes	10	Commercial-Residential	Yes
10	N Military Hwy	Poplar Hall Dr	Ring Rd	City of Norfolk	10	25	Yes	Yes	0	Commercial-Office	Yes
11	London Blvd	Effingham St	Chestnut St & Fort Ln	City of Portsmouth	6	35	Yes	No	10	Commercial-Office	Yes

ID	Route Name	Start	End	City or County	Number of Lanes at Mid-block	Speed Limit (mph)	Presence of Raised Median	Presence of Bus Stop	Total Width of Sidewalk (ft)	Land Use Interaction	VDOT PSAP Corridor
12	Airline Blvd	Bart St	Clifford St	City of Portsmouth	4	35	Yes	No	16	Commercial -Office	Yes
13	Victory Blvd	Hwy 17	Huron Dr	City of Portsmouth	6	35	Yes	Yes	10	Commercial -Office	Yes
14	Virginia Beach Blvd	Bird neck Rd N	Birch Lake Rd	City of Virginia Beach	6	25	Yes	Yes	8	Commercial -Office	Yes
15	E Washington St	County St & Liberty St	Factory St	City of Suffolk	2	25	No	Yes	22	Commercial -Office	Yes
16	Hwy 17	Cedar Ln & Sterling Point Dr	Exit of Portsmouth YMCA	City of Portsmouth	6	35	No	Yes	10	Education-Office	Yes
17	N Main St	W Constance Rd	Western Ave	City of Suffolk	4	25	Yes	Yes	12	Commercial -Office	Yes
18	Victory Blvd	Elmhurst Ln	Exit of Parking Lot close to Exxon	City of Portsmouth	7	35	Yes	No	4	Commercial -Office	Yes
19	Great Bridge Blvd	N Battlefield Blvd	Fairwinds Dr	City of Chesapeake	4	35	No	No	0	Commercial -Office	Yes
20	N Battlefield Blvd	Knell's Ridge Blvd	Exit of Parking Lot Close to Arby's Fast Food	City of Chesapeake	8	40	Yes	Yes	10	Commercial -Office	Yes
21	Kempsville Rd	Dunn Loring Dr	Tarleton	City of Virginia Beach	6	45	Yes	Yes	12	Office-Residential	Yes

ID	Route Name	Start	End	City or County	Number of Lanes at Mid-block	Speed Limit (mph)	Presence of Raised Median	Presence of Bus Stop	Total Width of Sidewalk (ft)	Land Use Interaction	VDOT PSAP Corridor
22	Pacific Ave	Norfolk Ave & 9th St	10th St	City of Virginia Beach	6	35	No	No	12	Commercial -Residential	Yes
23	Virginia Beach Blvd	First Colonial Rd	Louisa Ave	City of Virginia Beach	4	35	No	Yes	8	Commercial -Office	Yes
24	S Plaza Trail	Holland Rd	Exit of Parking Lot close to Wings Way Chicken Wings	City of Virginia Beach	5	35	Yes	No	8	Commercial -Residential	Yes
25	E Virginia Beach Blvd	Kempsvi lle Rd	Windborne Ln	City of Norfolk	6	30	Yes	No	0	Commercial -Office	Yes
26	Mercury Blvd	Aberdee n Rd	Exit of Parking Lot Close to Little Caesars Pizza	City of Hampton	9	45	Yes	Yes	24	Commercial -Office	Yes
27	Hampton Hwy	Yorktow n Rd & Theatre Rd	Exit of Maranatha Baptist Church of Yorktown	City of Hampton	4	55	Yes	No	0	Education-Office	Yes
28	Denbigh Blvd	Warwick Blvd	Exit of parking lots close to McDonald	City of Hampton	5	35	No	No	10	Commercial -Office	Yes
29	Jefferson Ave	Tech Center Pkwy & Hogan Dr	Exit of Parking Lot Close to Starbucks	City of Hampton	8	45	Yes	Yes	18	Commercial -Office	Yes
30	N Mallory St	County St	E Sewell Ave	City of Hampton	4	30	No	No	16	Commercial -Residential	Yes

ID	Route Name	Start	End	City or County	Number of Lanes at Mid-block	Speed Limit (mph)	Presence of Raised Median	Presence of Bus Stop	Total Width of Sidewalk (ft)	Land Use Interaction	VDOT PSAP Corridor
31	College Dr	Lake View Pkwy	Burbage Dr	City of Suffolk	6	50	Yes	Yes	10	Commercial -Office	Yes
32	Portsmouth Blvd	Suburban Dr	Virginia Ham Dr	City of Suffolk	4	55	Yes	No	0	Commercial -Office	Yes
33	Holland Rd	Staley Dr	Westgate Ave	City of Suffolk	4	45	Yes	Yes	0	Commercial -Residential	Yes
34	Carrollton Blvd	Eagle Harbor Pkwy	Exit Close to Sonic Drive-in Fast Food	Isle of Wight County	4	45	Yes	No	0	Commercial -Residential	Yes
35	Bridge Rd	Samira St	Bridgeport Way	City of Suffolk	4	45	Yes	No	10	Commercial -Office	Yes

APPENDIX D: A GUIDE TO USING THE PEDACT TOOL TO ESTIMATE PEDESTRIAN CROSSING DEMAND AND CHOICES

This guide demonstrates an Excel-based tool, PedAct, to estimate pedestrian crossing demand and choices at a mid-block location. The tool interface is divided into two main sections: the input section and the output section. The input section allows users to input variables such as demographics, land use context, road geometry, traffic conditions, and control and enforcement. The output section, which can be used to decide when to pursue countermeasures to enhance pedestrian safety, displays pedestrian crossing demand per hour, probability of crossing at mid-block at daytime, and probability of crossing at mid-block at nighttime.

Table D1 summarizes the definitions of input variables and data sources. The researchers recommend averaging the population in thousands and then averaging the other demographic inputs by population weights when the mid-block location of interest is on the boundary of different census tracts. Data sources include Census Reporter, Google Maps, field observations, and StreetLight.

Table D1. Definitions of Input Variables and Data Sources

Input Variables		Definition	Data Sources
Demographics	Population in thousands	Number of people in thousands in the census tract	Census Reporter
	Walk ratio	Means of transportation to work: proportion of trips choosing walking as a primary mode in the census tract, expressed as a value between 0 and 1.	Census Reporter
	Ratio of people aged 50 and over	Age: proportion of people aged 50 and over in the census tract, expressed as a value between 0 and 1.	Census Reporter
	Ratio of males	Sex: proportion of males in the census tract, expressed as a value between 0 and 1.	Census Reporter
	Proportion of residents identifying as white	Race and Ethnicity: proportion of residents identifying as white in the census tract, expressed as a value between 0 and 1.	Census Reporter
Land use context	Land use interaction	Dominant land use types (i.e., commercial, residential, educational, office, and green space) on each side immediately adjacent to the mid-block location	Google Maps or field observation
Road geometry	Total width of sidewalks on both sides (ft)	Summation of the sidewalk widths on both sides of the mid-block location in feet	Google Maps or field observation
	Number of lanes at the mid-block location	Number of traffic lanes at the mid-block location, including through lanes, turn lanes, bus lanes, etc.	Google Maps or field observation
	Presence of median	Whether there is a median at the mid-block location, even if it is a pedestrian refuge island but not a continuous median	Google Maps or field observation
	Distance to the nearest crosswalk (ft)	Distance from the mid-block location of interest (e.g., the midpoint of the mid-block, pedestrian generators) to the nearest crosswalk (i.e., marked crosswalk or any legal intersection crossing).	Google Maps or field observation

Traffic conditions	Number of vehicles per hour per lane	Average number of vehicles traversing per hour per lane for the time window of interest (e.g., different times of the day by hour)	Field observation, VDOT traffic data, or traffic counts from StreetLight data
Control and enforcement	Speed limit (mph)	Speed limit at the mid-block location in mph	Google Maps or field observation
	Pedestrian signal delay at intersection(s)	Pedestrian delay caused by the nearest adjacent intersection traffic signal in seconds. It is half the red interval for pedestrians at a signalized intersection and zero for an unsignalized intersection.	Field observation
	Presence of a safety message	Whether a safety message is present. Any message that raises pedestrian awareness about the high risk of mid-block crossing can be regarded as a safety message. e.g., general pedestrian safety campaigns cautioning against the high risks of mid-block crossing.	Field observation or Google Maps
Location calibration factor	Calibration coefficient for crossing choices at the mid-block location	Local calibration factor is used to calibrate the model to estimate crossing choices more accurately when local data is available	Field observation

An Illustrative Example

The researchers took one mid-block location (longitude: -76.12023252, latitude: 36.81861463) as an example to illustrate how to use this tool.

Step 1. Collect demographic inputs

The researchers recommend using Census Reporter to acquire the demographic inputs. Enter the address or coordinates of the mid-block location into the rectangular box highlighted in Figure D1. For the mid-block location in this example, type “-76.12023252, 36.81861463” to locate.

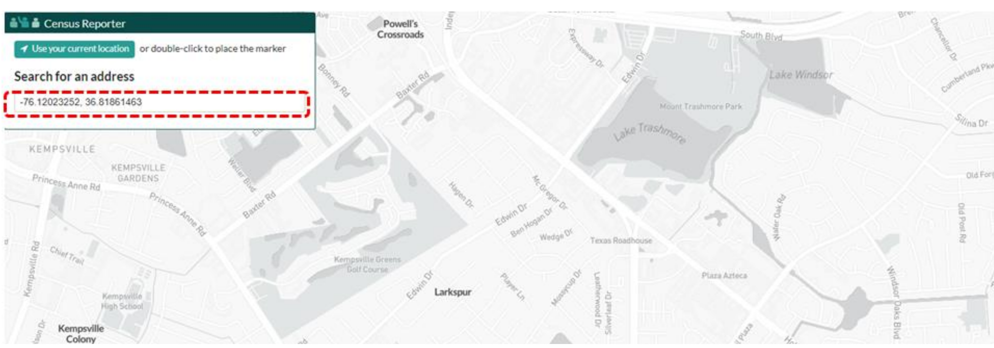


Figure D1. Locate the Mid-block Location of Interest, Map Data @2024 Open Street Map

From the dropdown, choose the corresponding census tract level as highlighted in Figure D2, rather than selecting the census block, ZIP code, county, or state. This will bring you to an interface with the census tract map and associated demographic data. As shown in Figure D3, the mid-block location of interest is on the boundary of Census Tract 458.08 and Census Tract 458.03. Clicking Census Tract 458.03 on the map will navigate you to the demographic data of the neighboring census tract.

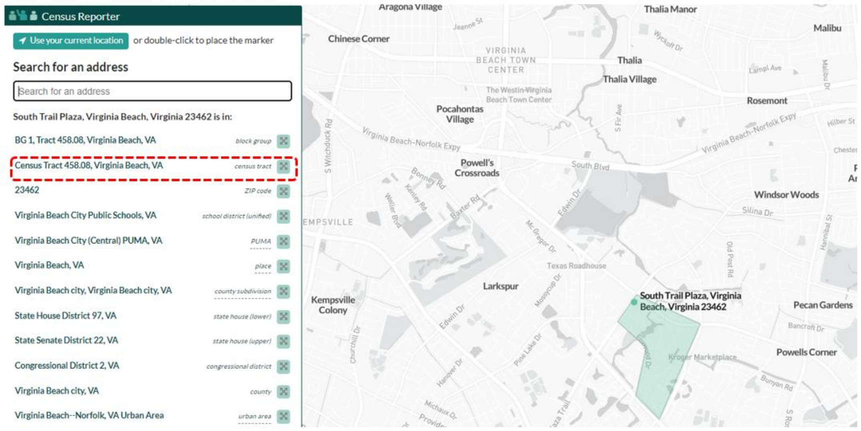


Figure D2. Crossing the Corresponding Census Tract, Map Data @2024 Open Street Map

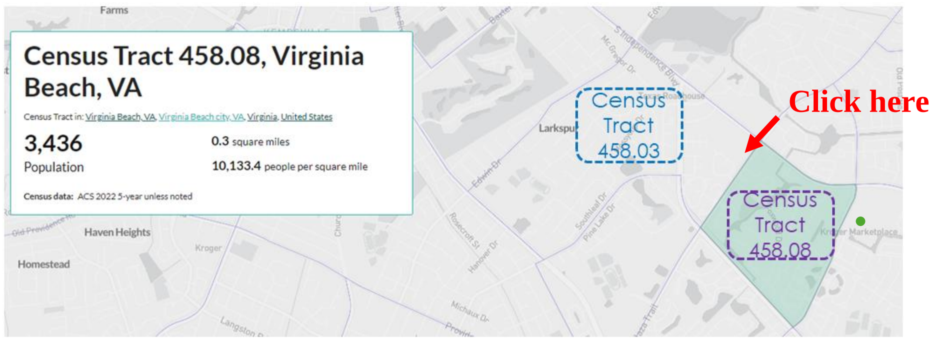


Figure D3 Navigate the Demographic Data of a Neighboring Census Tract, Map Data @2024 Open Street Map

Figure D4 shows the demographic data of the two neighboring census tracts, with input variables highlighted. It is recommended to average the population in thousands and then average the other demographic variables (i.e., the walk ratio, the ratio of people aged 50 and over, the ratio of males, and the ratio of the white race) by population weights for the two census tracts, as inputs in the tool.

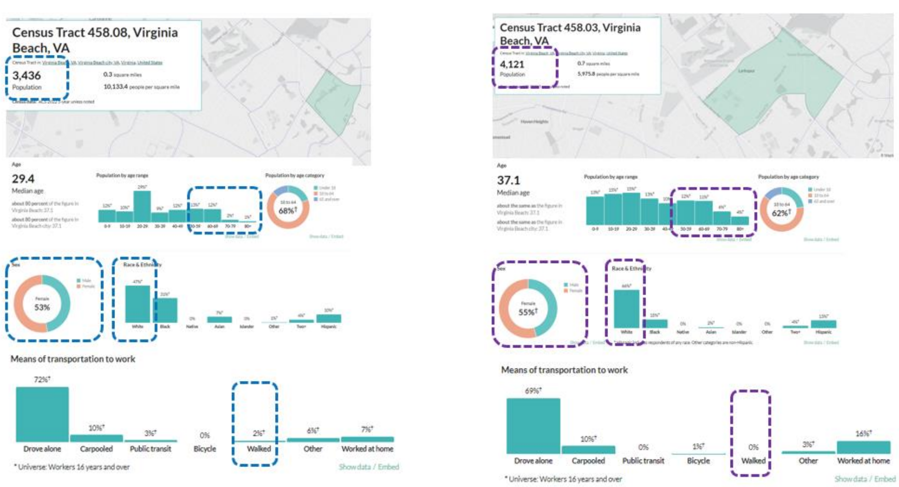


Figure D4. Demographic Data at the Two Neighboring Census Tracts, Map Data @2024 Open Street Map

Step 2. Collect other inputs, including land use context, road geometry, traffic conditions, control and enforcement

Other inputs, including land use interaction, total width of sidewalk on both sides, number of lanes at the mid-block location, presence of median, distance to the nearest crosswalk, number of vehicles per hour per lane, pedestrian signal delay at intersection, presence of safety message, can be collected from Google Maps, field observations, existing VDOT data, and StreetLight.

Figure D5 illustrates how to identify land use interaction. The dominant land use type includes commercial, residential, educational, office, green space, etc., immediately adjacent to the mid-block location of interest. For the mid-block location in this example, the dominant land use type is “commercial” on the one side and “residential” on the other. Consequently, the land use interaction for the mid-block location is “Commercial-Residential,” which falls under the “Others” category in the Excel-based tool.

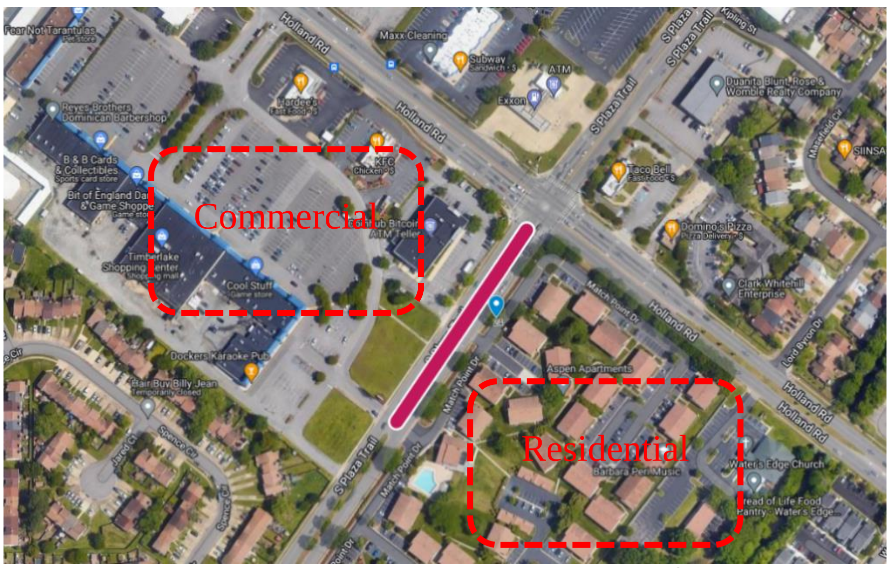


Figure D5. Identify Land Use Interaction, Map Data ©2023 Google

Figure D6 demonstrates the process of determining the total width of the sidewalk on both sides. By employing Google Maps' distance measurement tool, each sidewalk alongside the mid-block location measures 4 feet in width. Therefore, the total width of the sidewalk on both sides is 4 ft + 4 ft = 8 ft.

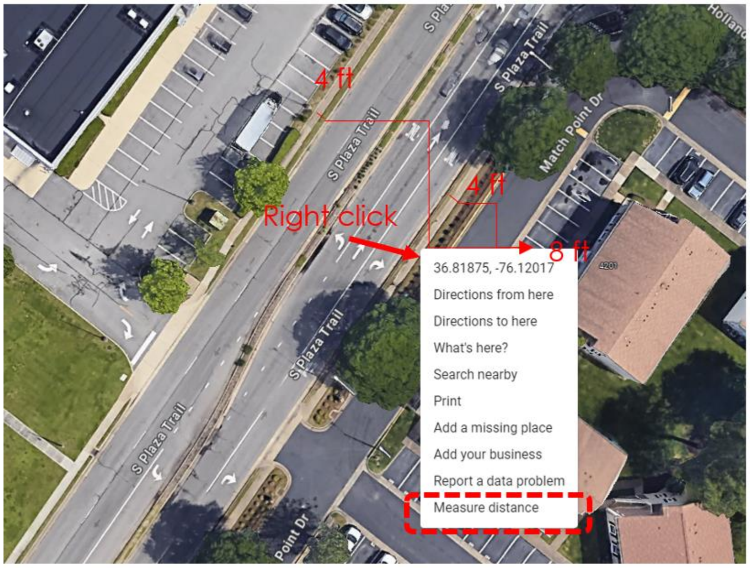


Figure D6. Determine the Total Width of the Sidewalk on Both Sides, Map Data @2023 Google

In addition, the number of traffic lanes at the mid-block location includes through lanes, turn lanes, bus lanes, etc. The median at the mid-block location means a pedestrian refugee island or a continuous median. Another critical input is the distance to the nearest crosswalk. This distance is measured from the mid-block crossing location of interest (e.g., the midpoint of the mid-block, pedestrian generators) to the nearest adjacent crosswalk or intersection. A typical choice is to measure the distance from the midpoint of the mid-block location to the nearest adjacent crosswalk, as shown in Figure D7.

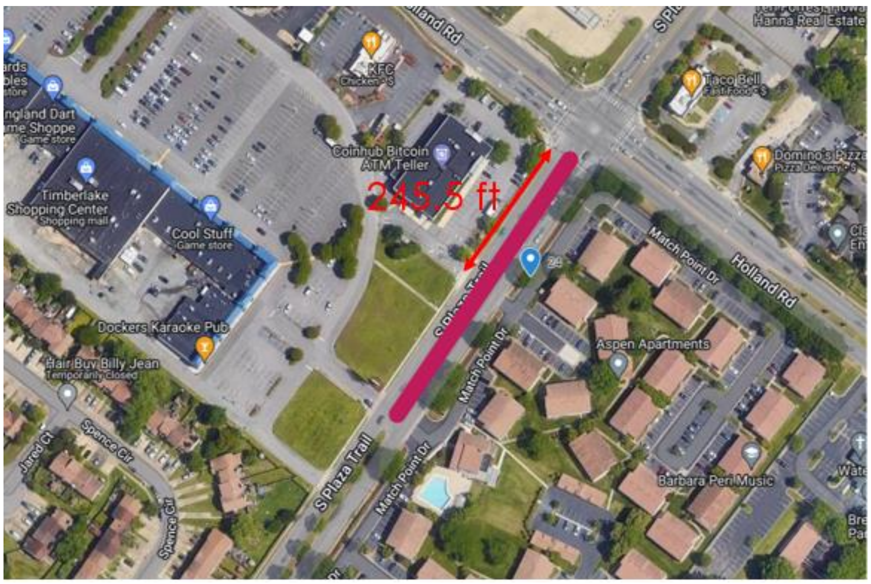


Figure D7. Measure the Distance to the Nearest Crosswalk, Map Data @2023 Google

The number of vehicles per hour per lane is the average number of vehicles traversing per hour per lane for the time window of interest (e.g., different times of the day by hour), which can be obtained by field observations, VDOT traffic counts, or StreetLight Data. Figure D8 depicts the hourly traffic volume distribution at the mid-block location in this example, as provided by StreetLight Data. For instance, if the time window of interest is from 14:00 to 22:00, the average number of vehicles per hour per lane during the time window is calculated to be 196.5 vehicles per hour per lane. Users should be cautious when investigating pedestrian crossing demand and probabilities of crossing at the mid-block location outside the time window (i.e., 14:00 – 22:00) because the researchers did not collect data to develop the models for other time windows.

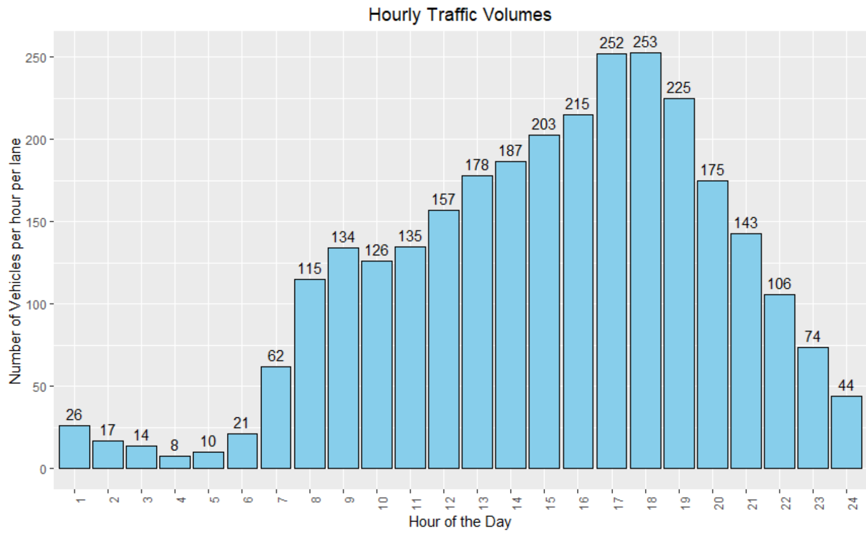


Figure D8. Hourly Traffic Volumes per Lane from StreetLight

Safety messages are those that raises pedestrian awareness about the high risk of mid-block crossing, e.g., general pedestrian safety campaigns cautioning against the high risks of mid-block crossing. The researchers assume that there is no safety message present for this site.

Step 3. Parameter Customization (Optional)

Step 3 is optional. Users can customize these parameters when such data are available for their localities. The default parameters used in this tool are presented in the "Parameters" sheet of the tool. Table D2 shows default parameters used for pedestrian crossing choices, which are obtained from an NCHRP report Web-Only Document 312.

Table D2. Default Parameters for Pedestrian Crossing Choices

Parameters for pedestrian crossing choices	Values
Expected delay for stop signs (s)	10
Yield rates (typically, between 0 and 0.6)	0.4
Pedestrian walking speed at sidewalk (ft/s)	4.4
Pedestrian walking speed when crossing (ft/s)	4.7
Ratio of walking in a group	0.29

When pedestrian crossing data are available, users can specify the local calibration factor to evaluate the effectiveness of countermeasures better. For example, the observed probability of crossing at the mid-block location of interest during the daytime is 71.0%, whereas the estimated probability of mid-block crossing during the daytime is 57.4%. There is not sufficient data collected at nighttime for this mid-block location. A grid search method can be used to select the optimal local calibration factor that can minimize the absolute difference between the observed and estimated probabilities of mid-block crossing in the daytime. As shown in Table D3, the optimal local calibration factor is found to be 0.35.

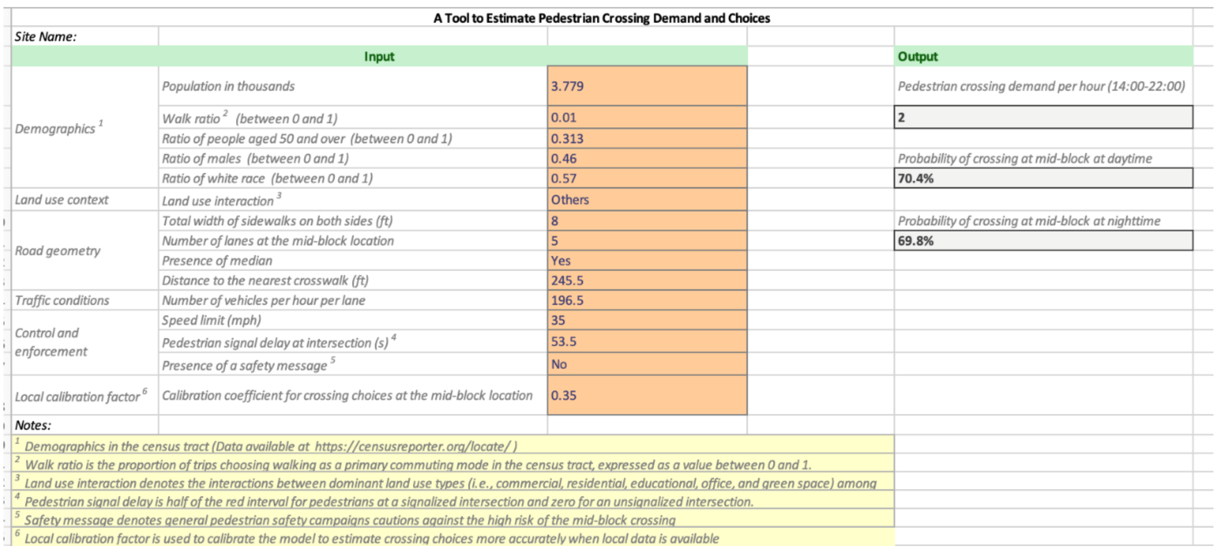
Table D3. Grid Search for Selecting the Optimal Local Calibration Factor

Local Calibration Factor	0	0.10	0.20	0.30	**0.35**	0.40
$\widehat{P_{daytime}}$	57.4%	61.2%	65 %	68.6%	**70.4%**	72%
$\lvert P_{daytime} - \widehat{P_{daytime}} \rvert$	13.6%	9.8%	6%	2.4%	**0.6%**	1.4%

Note: $P_{daytime}$ is the observed probability of mid-block crossing in the daytime, $P_{daytime} = 71\%$ in this example, $\widehat{P_{daytime}}$ is the estimated probability of mid-block crossing in the daytime.

Step 4. Identify Countermeasures and Evaluate their Effectiveness

The last step is to identify potential countermeasures according to the tool outputs and assess the effectiveness of these countermeasures in reducing the probabilities of mid-block crossing. For the mid-block location of interest, the inputs and outputs after applying the local calibration factor are presented in Figure D9. The pedestrian crossing demand is estimated to be 2 per hour, while the daytime and nighttime probabilities of crossing at mid-block are estimated to be 70.4% and 69.8%, respectively.



A Tool to Estimate Pedestrian Crossing Demand and Choices

Site Name:				
Input				**Output**
Demographics [1]	*Population in thousands*	3.779		*Pedestrian crossing demand per hour (14:00-22:00)*
	Walk ratio [2] (between 0 and 1)	0.01		2
	Ratio of people aged 50 and over (between 0 and 1)	0.313		
	Ratio of males (between 0 and 1)	0.46		*Probability of crossing at mid-block at daytime*
	Ratio of white race (between 0 and 1)	0.57		**70.4%**
Land use context	*Land use interaction [3]*	Others		
Road geometry	*Total width of sidewalks on both sides (ft)*	8		*Probability of crossing at mid-block at nighttime*
	Number of lanes at the mid-block location	5		**69.8%**
	Presence of median	Yes		
	Distance to the nearest crosswalk (ft)	245.5		
Traffic conditions	*Number of vehicles per hour per lane*	196.5		
Control and enforcement	*Speed limit (mph)*	35		
	Pedestrian signal delay at intersection (s) [4]	53.5		
	Presence of a safety message [5]	No		
Local calibration factor [6]	*Calibration coefficient for crossing choices at the mid-block location*	0.35		

Notes:

[1] Demographics in the census tract (Data available at https://censusreporter.org/locate/)
[2] Walk ratio is the proportion of trips choosing walking as a primary commuting mode in the census tract, expressed as a value between 0 and 1.
[3] Land use interaction denotes the interactions between dominant land use types (i.e., commercial, residential, educational, office, and green space) among
[4] Pedestrian signal delay is half of the red interval for pedestrians at a signalized intersection and zero for an unsignalized intersection.
[5] Safety message denotes general pedestrian safety campaigns cautions against the high risk of the mid-block crossing
[6] Local calibration factor is used to calibrate the model to estimate crossing choices more accurately when local data is available

Figure D9. Input and Output for the Mid-block Location of Interest

Table D4 suggests a list of countermeasures based on crossing demand and mid-block crossing probabilities. For the selected mid-block location, the estimated crossing demand is much lower than the average 3.5 per hour, while the mid-block crossing probabilities are much higher than the baseline 46%. This site is categorized as having a "low crossing demand and high mid-block crossing probability," and thus, countermeasures that encourage safe crossings at nearby locations should be recommended.

Table D4. Identification of Countermeasures Based on Crossing Demand and Mid-block Crossing Probability

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Crossing Demand (As a reference, the average crossing demand of the field observation sites is 3.5 per hour)</td></tr>
<tr><td>Low</td><td>High</td></tr>
<tr><td rowspan="2">Mid-block Crossing Probability (As a reference, the probability of mid-block crossing at the selected sites is 46%)</td><td>Low</td><td>No countermeasures recommended</td><td>No countermeasures recommended</td></tr>
<tr><td>High</td><td>Encourage safe crossings at nearby locations:
• Reduce pedestrian delay at the nearest intersections (e.g., provide a pedestrian signal push button, adjust signal timing, etc.)
• Locate pedestrian generators (e.g., bus stops) closer to intersections with crosswalks.
• Prevent mid-block crossing using physical fencing.
• Education and communications (e.g., general pedestrian safety campaigns cautioning against the high risks of mid-block crossing)</td><td>Improve the safety of mid-block crossings:
• Improve infrastructure and design (e.g., raised median, road diet, speed calming, enhanced lighting conditions, adding sidewalks, etc.)
• Improve control and enforcement (e.g., provide marked crosswalks with high visibility, advanced stop/yield bars, pedestrian hybrid beacon (PHB), rectangular rapid flash beacon (RRFB), pedestrian warning signs, solar-powered dynamic feedback signs, driver-yielding enforcement, etc.)</td></tr>
</table>

After using Table D4 to identify a series of countermeasures that include reducing the traffic signal delay (e.g., by providing a pedestrian push button), reducing the distance to the nearest crosswalk (e.g., relocating trip generators such as bus stops), and sending safety messages (e.g., raising the awareness on the high risk of mid-block crossing via pedestrian safety campaigns), the tool can be used again to estimate mid-block crossing probabilities for various scenarios by changing the input variables. Table D5 shows the proposed countermeasures and their estimated effectiveness in reducing mid-bock crossing probabilities. Combining the series of countermeasures mentioned above, it is expected to reduce the daytime mid-block crossing probability to 48% from the baseline of 71%.

Table D5. Potential Countermeasures and Their Effectiveness in Reducing Mid-block Crossing Probabilities

Scenarios	$P_{\widehat{daytime}}$ (Estimated probability of mid-block crossing at daytime)
No countermeasure	71%
Countermeasure 1 (-20 s traffic signal delay)	68%
Countermeasure 2 (-40 s traffic signal delay)	65%
Countermeasure 3 (-100 ft distance to the nearest crosswalk)	64%
Countermeasure 4 (-200 ft distance to the nearest crosswalk)	58%
Countermeasure 5 (sending safety messages)	66%
Countermeasure 6 (-40 s traffic signal delay, -200 ft distance to the nearest crosswalk, and sending safety messages)	48%