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A Hybrid Approach to Improve Flood Forecasting by Combining a Hydrodynamic Flow Model and Artificial Neural Networks

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Systemic Opportunities to Improve Older Pedestrian Safety: Merging Crash Data Analysis and a Stakeholder Workshop

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ABSTRACT

This paper presents a framework for improving older pedestrian safety in regard to serious (fatal and incapacitating) crashes, using Oregon as a case study. Upon review of state and federal practices pertaining to older pedestrian safety, four years of crash data identified 112 older (≥ 65 years) pedestrian serious injury crashes. These data were explored for factors that might be addressed systemically using two methods. First, raw frequencies in the crash data were assessed to determine trends and crash-related factors that are overrepresented. Second, a random forest analysis is conducted to determine important variables for predicting older pedestrian serious injury crashes. Using these crash-related factors, a workshop was held with 18 local stakeholders and experts. As part of the workshop, key crash trends, potential causations, and potential countermeasures by priority of implementation were determined based on perspectives from workshop participants. Three key systemic solutions were identified to improve older pedestrian safety, including improving pedestrian visibility and illumination, implementing treatments for left-turns, and shortening pedestrian crossing distances across the state. The framework presented in the current study can be adopted by other agencies to systemically address a wide variety of safety concerns.

Keywords: older pedestrians, serious injury, workshop, countermeasures**,** pedestrian safety

INTRODUCTION

In 2018, 6,907 people 65 and older were killed in traffic crashes in the United States, which accounted for 19 percent of all traffic fatalities. Between 2009 and 2018, older pedestrian fatalities increased by 65 percent overall (*1*). Older pedestrians that are involved in crashes with motor vehicles are more likely to result in a fatality when compared to other age groups due to increased physical frailty (*2*) and are particularly susceptible to collisions with motor vehicles due to slower walking speeds, difficulty meeting situational demands, and are at increased risk for falling while walking (*3*). Some older pedestrians may also have an inhibited ability to make safe road crossing judgments and decisions due to visual and hearing degradation combined with cognitive decline (*3*). Studies show that when crossing a street, older pedestrians accept shorter time gaps in oncoming traffic as vehicle speeds increase (*4*).

Identifying where infrastructure improvements need to be made to accommodate older pedestrians is a challenge for many agencies. Successful pedestrian programs, such as one in Sacramento, CA, rely on older pedestrians to self-report problems with pedestrian infrastructure in their respective communities (*2*). Lowering speed limits on roadways, separating pedestrians by time and space (for example, utilizing protected or leading pedestrian intervals at signalized intersections), increasing the visibility of pedestrians to drivers, installing pedestrian countdown signals, and reducing vehicle speeds on roadways with high pedestrian volumes, are all highly effective ways to increase safety for older pedestrians (*3–7*). However, the success of these strategies is dependent on in situ context in case of lowered speed limits and whether there are a significant proportion of older pedestrians in the population, which may render these strategies to be less effective (*8*).

In Oregon, from 2013 to 2016, 112 pedestrian fatalities and serious injury crashes occurred. Due to the rate per capita increases of traffic fatalities and serious injuries for older drivers and pedestrians 65 years of age and older, the Special Rule for Older Drivers and Pedestrians in the "Fixing America's Surface Transportation (FAST)" Act was triggered (*9*). This rule required agencies to develop systemic strategies to address year over year increases. This manuscript documents a framework for developing strategies for addressing older pedestrian crashes.

Four years of older pedestrian crash data in Oregon were analyzed to determine trends and factors overrepresented in the raw crash data resulting in fatal and serious injury crashes. A random forest analysis was conducted to determine important factors in predicting older pedestrian fatal and serious injury crashes. Using the crash factors that were identified as overrepresented and important predictors of older pedestrian serious injury crashes, a list of countermeasures was developed. Crash factors were matched to potential countermeasures based on cost and anticipated implementation duration. Finally, a workshop was conducted with 18 key stakeholders and experts who are responsible for policy and design guidance to identify opportunities for improving policies and procedures to increase older pedestrian safety.

METHODS

The framework for developing policy recommendations for improving older pedestrian safety consists of four steps. Older pedestrian crash characteristics were summarized based on records in the Oregon crash data from 2013 to 2016. As part of the descriptive analysis, a random forest model was constructed to identify variable importance in older pedestrian crashes. Following several recent publications from the National Highway Transportation Safety Administration (*10–*

12), age groups were compared to older pedestrian crashes as follows: 16 years to 24 years, 25 years to 44 years and 45 years to 64 years.

Next, a comprehensive list of potential countermeasures was identified from the literature. Key sources include the CMF Clearinghouse and Oregon DOT's All Roads Transportation Safety (ARTS) program (*13*, *14*). These countermeasures were summarized by category, associated crash modification factor (CMF), its rating, and its effectiveness. Not all possible countermeasures have a quantitative CMF, especially those related to policy or education. The scope of the countermeasure (i.e., policy-driven, project-level, systemic) and if the countermeasure is currently listed in one of ODOT's systemic approaches was also indicated. The countermeasures were then matched to crash factors identified from the crash data analysis.

A workshop was hosted with the objective of bringing together the various stakeholders and experts with responsibilities for policy and design guidance that relate to older pedestrian safety; present results of the data analysis, best practices (identified in the literature review), and potential countermeasures (obtained from the CMF Clearinghouse and ODOT's ARTS program); and, identify possible opportunities for improving policies and procedures at ODOT. In consultation with the ODOT research coordinator and the Technical Advisory Committee (TAC), a list of participants was developed. The TAC consisted of five professionals with technical expertise of the research project and are listed in the acknowledgements section. In addition to the ODOT personnel who were responsible for policy and design guidance pertaining to older pedestrian safety, the research team also invited representatives from counties that were overrepresented in either older driver or older pedestrian crashes, agencies engaged with improving older pedestrian (or driver) safety, such as the American Automobile Association, the American Association of Retired Persons (AAA, AARP), and the League of Oregon Counties. A total of 31 stakeholders and experts were invited to participate in the workshop. Invitees included representatives from AAA, AARP, the Area Agency on Aging Statewide, representatives from counties with an overrepresentation, various ODOT personnel, and members of the TAC. Members from the TAC included a highway safety coordinator, a signing engineer, a representative from ODOT's Older Road Users Program, a representative from the ODOT Department of Motor Vehicles Medical Program, and a safety and design engineer with the Federal Highway Administration. For the workshop, 18 stakeholders and experts (including the TAC) attended.

The 18 participants were divided into four groups and three activities were designed for the participants to elicit feedback. During the first activity, participants at each table independently reviewed crash data information sheets and documented the patterns that seemed notable. Next, participants discussed with their groups the crash trends/overrepresentations that they individually identified as unexpected, or expected, and speculated on the causation. The participants then identified the most important trend or overrepresentations from each table's perspective and recorded them on a response sheet. For the second activity, participants were asked to imagine that they were either the Governor or ODOT Director for a day and, ignoring cost and feasibility, brainstorm the changes that they would make to improve older pedestrian safety. The participants were provided with a list of categories to aid the brainstorming process. These categories included licensing and assessment, education and awareness, intersections, roadway design and signing, roadway lighting, and aging in place. Participants were then asked in their designated groups to discuss their proposed solutions and determine if there were any shared ideas. Those shared ideas were documented on the data sheet at each table. For the final activity in the breakout session, participants individually reviewed the countermeasure list using their own expertise to highlight the countermeasures that would be implementable as a systemic treatment, through policy changes, or design guidance. Finally, the participants discussed systemic actions or changes to specific design standards or policies and documented these using the data sheets provided at each table.

Following the breakout sessions members of the research team synthesized findings from each group pertaining to older pedestrian crash trends and brainstormed solutions. These results were presented back to the participants. Based on feedback obtained regarding proposed solutions from the participants, the research team created posters with the proposed solutions aggregated by category. Participants were then asked to use three different colored post-it notes, where each color represented a priority level, to rank order their top three proposed solutions. These recommendations and proposed solutions are further detailed in Monsere et al. (*15*).

RESULTS

The results from the crash data analysis are presented first, followed by the workshop findings.

Crash Data Analysis

An analysis of the crash data from 2013 to 2016 yielded 112 fatal and serious injury crashes for pedestrians. Figure 1 and

Figure 2 present the results of a basic descriptive analysis of the crash data. The majority of older pedestrian fatal and serious injury crashes occurred from 3:00 p.m. to 5:59 p.m. (26.8%) or 6:00 p.m. to 8:59 p.m. (21.4%). The largest percentage of older pedestrian fatal and serious injury crashes took place on a Friday at roughly 24%. The majority of older pedestrian fatal and serious injury crashes happened on urban roadway classifications. Specifically, 34% occurred on urban principal arterials, 25% on urban minor arterials, and 15% on urban major collectors. For rural classifications, the highest percentage observed is approximately 6% on rural principal arterials and approximately 6% on rural major collectors. Pedestrian action describes what the pedestrian was doing, their condition, or other factors affecting the individual at the time of the crash (*15*). The majority of pedestrian actions occured at or near intersections, the roadway character with the highest proportion of older pedestrian fatal and serious injury crashes. Approximately 24% of older pedestrians were crossing between intersections when the crash occurred, about 23% were crossing at an intersection with no traffic signal, and roughly 21% were crossing at an intersection with a traffic signal. Nearly 52% occurred during clear conditions, about 29% happened during cloudy conditions, approximately 14% took place under rainy conditions, and roughly 5% occurred during foggy conditions. Approximately 62% of older pedestrian fatal and serious injury crashes involved a male, and roughly 38% involved a female.

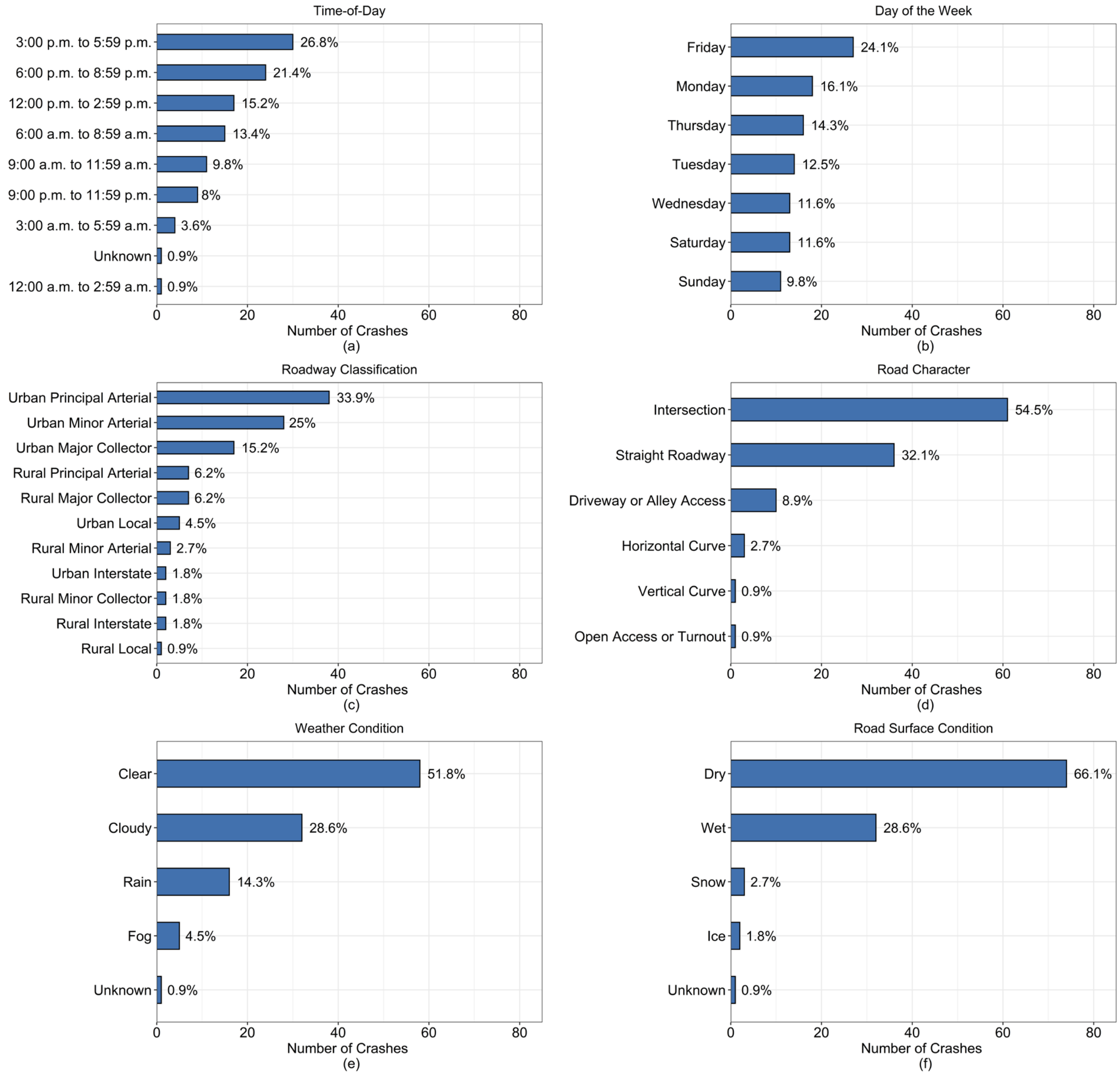

Figure 1: Older pedestrian fatal and serious injury crashes and (a) time-of-day, (b) day of the week, (c) roadway classification, (d) road character, (e) weather condition, and (f) road surface condition

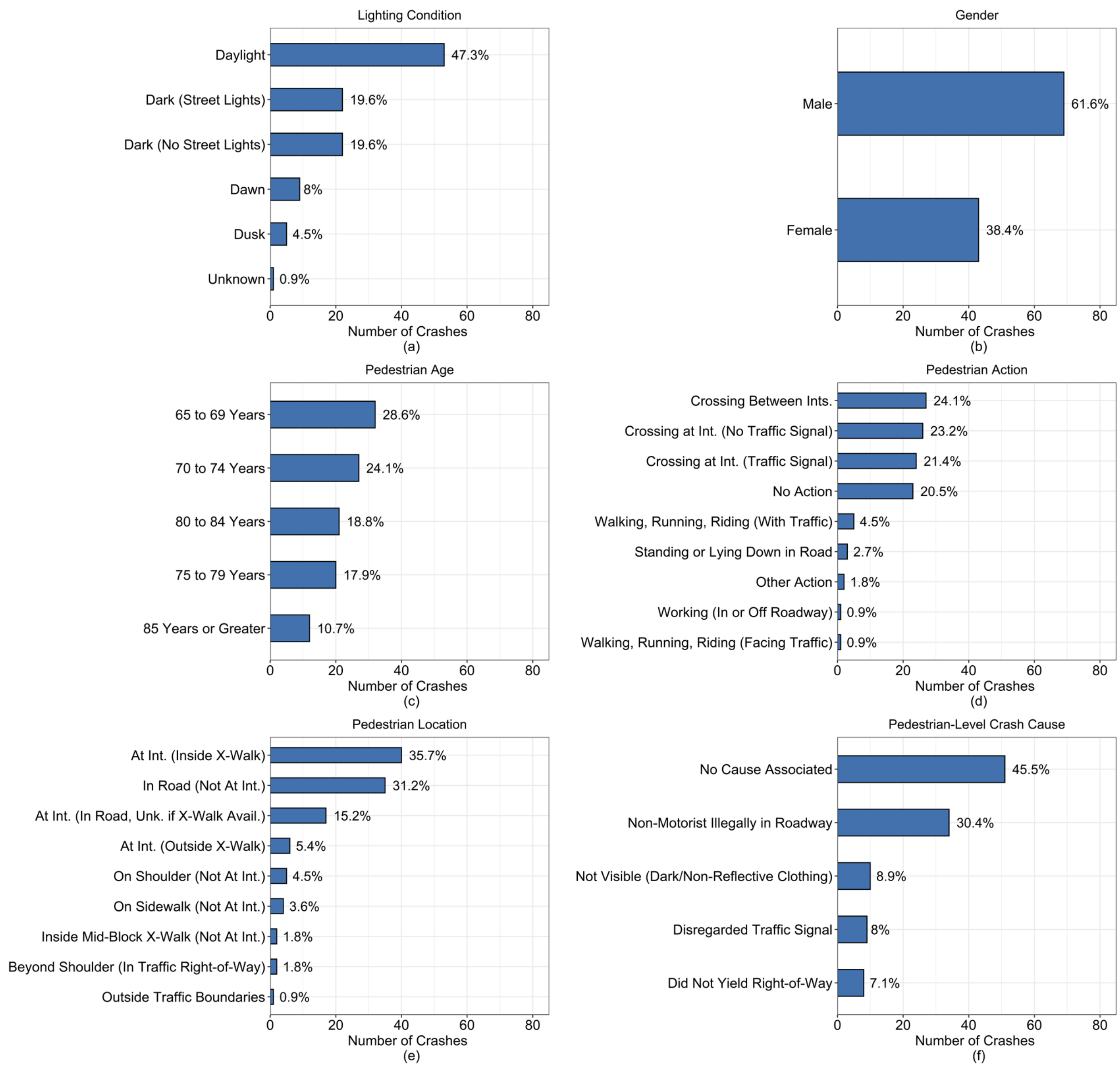

Figure 2: Older pedestrian fatal and serious injury crashes and (a) lighting condition, (b) gender, (c) age, (d) pedestrian action, (e) pedestrian location, and (f) pedestrian-level crash cause

Next, older pedestrian fatal and serious injury crashes were compared to fatal and serious injury crashes for other age groups, namely: 16 to 24 years, 25 to 44 years, and 45 to 64 years. Except for the 16 to 24 years age group, all other age groups show increasing trend of pedestrian fatal and serious injury crashes as seen in Figure 3.

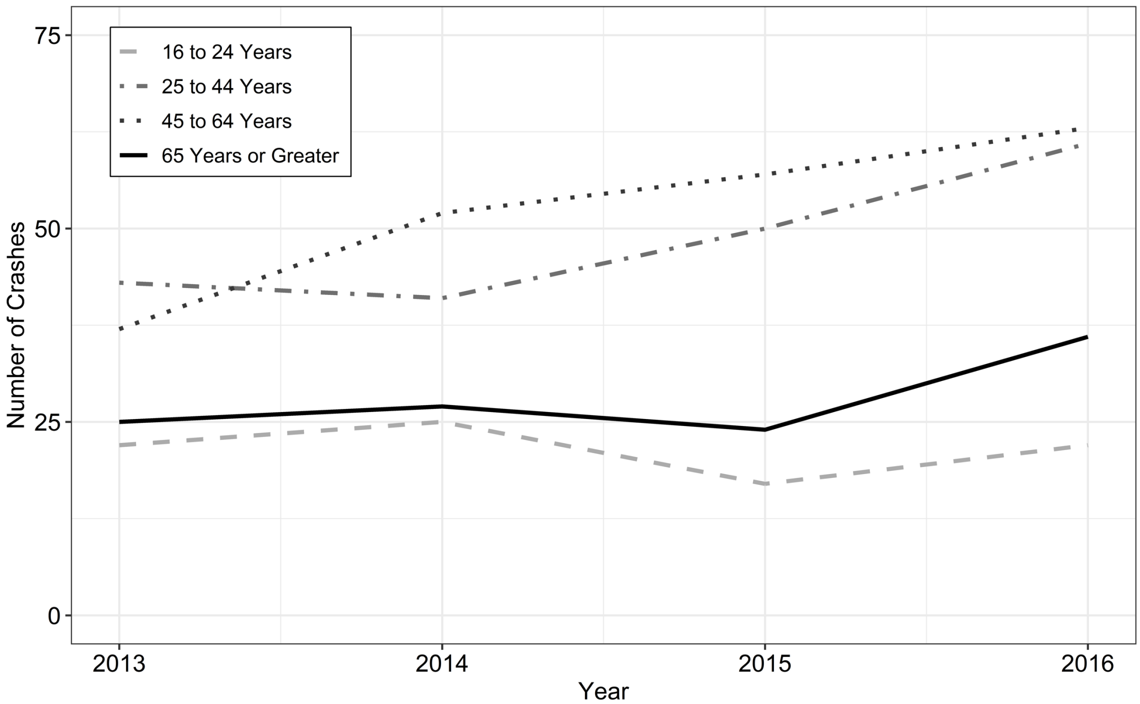

Figure 3: Pedestrian fatal and serious injury crashes by age group

To determine variable importance in regard to older pedestrian fatal and serious injury crashes, a random forest analyses was conducted. The use of a random forest, or other machine learning method, to identify important predictors and/or complement traditional models has become prevalent in the transportation safety literature (*17*-30). The current study applies this approach to identify important variables in predicting older pedestrian serious injury crashes.

Variable importance refers to variables that are deemed most important for predicting older pedestrian serious injury crash outcomes based on metrics detailed below. A random forest analysis is an ensemble-based machine learning technique. This method utilizes a set of data, where a dependent variable and a set of explanatory variables are defined. The explanatory variables are then used to predict the dependent variable through the random forest analysis. In the case of the current study, the dependent variable is binary (1 if the older pedestrian sustained a fatal or serious injury, 0 otherwise), and the set of explanatory variables are the crash characteristics. Through the prediction process of the random forest analysis, variable importance is determined.

Variable importance is assessed by two metrics: mean decrease in accuracy and mean decrease in the Gini Index. These can often be referred to as accuracy-based importance and Gini-based importance. Accuracy-based importance is associated with the prediction accuracy of a specific outcome (*31*). This is computed during the out-of-bag error calculation (a method to measure prediction error on each training sample) in the random forest algorithm (*32*). The higher the accuracy due to exclusion of a specific variable, the more important that variable is (*32*, *33*). The Gini Index (or coefficient) refers to the measure of each variable in regards to contribution of homogeneity (reduction in variance) in the tree nodes and leaf nodes of the random forest (*32*). Variables that result in tree nodes with a higher homogeneity lead to a higher decrease in the Gini Index.

The use of a random forest in this work stems from the disadvantages of decision trees. The major disadvantage of decision trees is their susceptibility to overfitting and that they are generally non-robust (*34*). On the other hand, random forests, as stated previously, use an ensemble-based learning technique to generate a stronger and more robust model (*34*). This is accomplished in random forests using multiple decision trees and averaging the results.

Table 1 presents the results of the random forest analysis. Shown are the five most important variables for the two variable importance metrics. Based on mean decrease in accuracy, the most important variables for older pedestrian serious injury crash prediction are dark lighting conditions with no streetlights, intersection crashes, crashes in which the pedestrian was at an intersection and inside the crosswalk, cloudy weather, and daylight conditions. The most important variables in terms of the Gini Index are roadway classification (urban principal arterials and urban minor arterials), dark lighting conditions with no streetlights, cloudy weather, and crashes in which the pedestrian was illegally in the roadway. Two crash-related characteristics were determined to be important for both metrics: dark lighting with no streetlights and cloudy weather.

Table 1: Variable Importance on Older Pedestrian Fatal and Serious Injury Crashes Based on Random Forest Analysis

Top Important Variables based on Mean Decrease in Accuracy	Top Important Variables Based on Gini Index
1. Dark (No Street Lights)	1. Urban Principal Arterial
2. Intersection	2. Urban Minor Arterial
3. At Intersection (Inside Crosswalk)	3. Dark (No Street Lights)
4. Cloudy	4. Cloudy
5. Daylight	5. Illegally in Roadway

Workshop Findings

Stakeholders and experts at the workshop were tasked with three activities, each to be completed and documented by the four groups. Workshop findings are presented by activity and group, followed by a summary of responses that were consistent among groups. The first activity involved each group documenting important patterns in the crash data materials provided to each group. The crash data materials included tables and plots pulled from crash data analysis. Specifically, each group was directed to "*Discuss the crash trend/overrepresentation you identified as unexpected or expected. Take notes on your observations and feel free to speculate on causation.*" Additionally, Activity 1 asked each group to "*Identify the most important trend/overrepresentations from the perspective of your group. Make brief notes on the response sheet for your group.*" Table 2 and Table 3 show the important crash trends and potential causations as identified by the stakeholders and experts. These tables represent vote counts by group and potential causations by group, not individual participants. Only one group idntified lighting and crossing while not in the intersection. In terms of expected or unexpected crash trends, and potential causation, three trends were identified most often: (1) crossing between intersections, (2) daylight, and (3) urban areas. Workshop participants speculated on potential causation for crashes in which older pedestrians were crossing between intersections, including the following: jaywalking, crossing with no signal, and dificulty estimating speed and gaps. Likewise, workshop participants speculated on potential causation for older pedestrian crashes that occurred on urban classifications; specifically, pedestrians may be crossing parallel to the mainline. One group posed questions to be considered for future research, such as at-fault older pedestrian crashes being a result of low enforcement, if rural facility crashes are related to older pedestrians checking their mail, and if there is any correlation between homeless and older pedestrians.

Table 2: Most Selected Important Crash Trends by Stakeholders

Crash Trend	Times Selected
Crossing between Intersections	2
Daylight	2
Urban Areas	2

Table 3: Potential Causation of Most Selected Crash Trends

Crash Trend	Potential Causation
Crossing between Intersections	• Jaywalking • Crossing with No Signal • Harder to Estimate Speed and Gaps
Urban Areas	• Crossing Parallel to Mainline

For Activity 2, each group was directed to *"As a group, discuss your proposed solutions. Determine if there are any shared ideas. Make brief notes on the datasheet for your group."*

A summary of most selected solutions for Activity 2 is shown in Table 4. Table 4 represents counts by group, not individual participants. Of the solutions proposed, four solutions were proposed by at least three groups. The first solution proposed by three groups is access management and/or driveway spacing. One group proposed, specifically, access management with a focus on reducing driveway density. The remaining two groups that proposed access management and/or driveway spacing as a solution did not provide additional comments. However, one group proposed removing driveways from T-intersections. The second solution proposed by three groups was crosswalk spacing. The second group proposed an "adequate" crosswalk spacing, each with additional protection (e.g., RRFBs, signals). The third group proposed an increase in marked or enhanced crosswalk spacing but did not provide additional comments. The final group proposed crosswalk spacing frequency, with an emphasis on spacing at consistent, safe intervals. The third solution proposed by three groups is related to lighting/visibility at intersections. The first group proposed higher visibility for pedestrians at intersections (this group also proposed wider waiting areas on the curb and better sightlines). The second group also proposed additional lighting but did not provide additional comments. The third group proposed improved intersection lighting with the premise of increasing driver expectation of encountering pedestrians. This group also proposed improved lighting at midblock crossings and along the roadway. The final solution proposed by the three groups was crossing visibility. The first group recommended improved crossing visibility, where the focus should be on rural arterials. The second group proposed a requirement that an unspecified percentage of reflective clothing be worn to increase pedestrian visibility while crossing. The third group suggested improving crossing visibility through the addition of lit signage, flashing signals (e.g., RRFBs), and maintaining reflective striping.

Table 4: Most Frequent Proposed Solutions for Older Pedestrians

Proposed Solution	Groups Selected
Access Management, Driveway Spacing	3
Crosswalk Spacing	3
Lighting/Visibility at Intersections	3
Crossing Visibility	3
Turn Restrictions	2

For Activity 3, each group was directed to *"As a group, discuss and identify possible systemic actions (regular implementation of treatments to workflows) or changes to design standards or policies. Make brief notes on the datasheet for your group. These ideas will be summarized and synthesized for the workshop wrap-up."* After each group submitted their datasheet, all sheets were summarized. Workshop participants were then given three votes each (indivudal, not group) and asked to vote on potential solutions. Each workshop participant had a top priorty vote, a second priority vote, and a third priority vote. At the conclusion of the workshop, votes were counted and solutions prioritized.

A summary of potential solutions for older pedestrians, and votes by priority, is shown in Table 5. Table 5 represents individual participant counts. Five solutions received at least two top-priority votes, where four of these received three top-priority votes. These solutions included the increased use of protected left turns (eliminate permissive movements), illumination to increase pedestrian visibility, and eliminating driveway access near intersections. The solutions with two top priority votes included shorter crossing distances/curb extensions/medians and lower speed limits. In terms of second-priority votes, four solutions received more votes compared to others. The solution with the highest number of second-priority votes was shorter crossing distances/curb extensions/medians (received six votes). The remaining solutions each received four second-priority votes, including adequate pedestrian crossings at regular intervals, illumination to increase pedestrian visibility, and eliminating free-flow turn and right-turn slip lanes. Lastly, in terms of third-priority votes, three solutions received more votes compared to others. In addition, each of these solutions belong to the intersection-related category. Of these, shorter crossing distances/curb extensions/medians received six votes, and increasing the use of protected left turns (eliminating permissive movements) and adequate pedestrian crossings at regular intervals each received three votes.

Table 5: Potential Solutions for Older Pedestrian Safety by Priority

Solution	Top Priority	Second Priority	Third Priority
Intersections			
Extended Crossing Times	0	1	1
Shorter Crossing Distances/Curb Extensions/Medians	**2**	1	**6**
Adequate Pedestrian Crossing at Regular Intervals	1	**4**	**3**
Increased Use of Protected Left Turns (Eliminate Permissive Movements)	**3**	**6**	**5**
Mid-Block Crossings	0	0	0
Education			
Educate on Crosswalk Use	0	0	1
Roadway Lighting			
Illumination to Increase Pedestrian Visibility	**3**	**4**	1
Roadway Design			
Lower Speeds	**2**	2	2
Grade Separate at Intersections	0	0	0
Eliminate Free Flow Turns and Right-Turn Slip Lanes	0	**4**	0
Eliminate Driveway Access in Close Proximity to Intersections	**3**	2	0
Make Pedestrian Safety More of a Priority	1	1	0
Other			
Better Transit Route and Stops	1	1	2
Reduce Barriers to Obtaining Rides	1	0	2

[*] Value in indicate countermeasures with the highest number of top priority votes
[*] Value in indicate countermeasures with the highest number of second priority votes
[*] Value in indicate countermeasures with the highest number of third priority votes

DISCUSSION

Based on the crash data analysis and workshop findings, systemic treatments to improve older pedestrian safety were identified. The systemic approach allows agencies to implement the selected safety improvements at multiple locations with similar risk characteristics. As these countermeasures will be widely implemented, the focus is on selecting low-cost solutions. Thus, the selected countermeasures to improve older pedestrian safety included improving visibility and illumination, treatments for left turns, and shortening crossing distances. From the perspective of universal design, treatments aimed at benefitting older road users, should benefit all road users. The focus here was to identify low-cost systemic treatments to improve older pedestrian safety, and these treatments were selected based on crash causes that were overrepresented in older pedestrian crashes. Additional details on specific countermeasures by crash cause are documented in the final technical report (*15*).

Improving Pedestrian Visibility and Illumination

Lighting is a significant factor in older pedestrian fatal and serious injury crashes. Crash data analysis showed that 20% of the crashes occurred in the dark with no street lighting, and an additional 8% and 5% of the crashes occurred during dawn and dusk, respectively, where the ambient lighting is low. Improving pedestrian visibility and illumination was voted as the top priority by the workshop participants. Countermeasures that improve illumination and visibility of the pedestrian include improved lighting at intersections and near crossing locations and installing RRFB flashing beacons or other active warning devices such as flashing LED mounted "Pedestrian Crossing" warning signs (*35*). Increased visibility of pedestrians to drivers has shown to reduce crashes up to 13% (*14*, *36*), and Monsere et al. (*37*) estimated a CMF of 0.71 due to the implementation of RRFBs.

Treatments for Left Turns

Vehicles turning left accounted for 19% of the older pedestrian fatal and serious injury crashes. Eliminating the use of permissive left turns and increasing the use of protected left turns can improve older pedestrian safety as drivers often focus on the oncoming traffic looking for gaps and thereby miss the crossing pedestrians during permissive left turns. This countermeasure also improves older driver safety by reducing their cognitive load. If permissive left turns are used, adding a flashing yellow arrow indication for right turns can improve driver comprehension and behavioral response in the presence of pedestrians (*38*). Additionally, slowing down the left-turning vehicles may be another strategy to improve pedestrian safety. Cities such as Portland and New York City have been using wedges and centerlines to decrease vehicle speeds and improve pedestrian safety. Implementing protected pedestrian phases and leading pedestrian intervals near older communities can also improve safety, as implenetation of measures to separate pedestrians by time and space through utilizing protected or leading pedestrian intervals has shown to reduce the expected number of crashes up to 13% (*14*, *36*).

Shorten Crossing Distances

The proportion of older pedestrian fatal and serious injury crashes when the pedestrians were in the roadway were statistically significantly different when compared to the proportions of the crashes for pedestrians between 25-44 years of age and 45-64 years of age. Shortening the crossing distance for the pedestrians will shorten their exposure time, thus increasing their safety. Specific countermeasures include installing pedestrian islands in the median to shorten the crossings and provide refuge, curb extensions on commercial streets and bus routes and raised crosswalks and road diets near older communities (*35*). Pedestrian islands in the median of wide and busy streets have shown to decrease the expected number of crashes up to 14% (*14*, *36*), and raised crosswalks and road diets up to 46% (*14*, *36*).

CONCLUSIONS

The objective of this research was to identify strategies to improve older pedestrian safety. To accomplish this objective, a review of the literature, crash data analysis, selection of potential countermeasures, and workshop were conducted to arrive at recommendations for improving older pedestrian safety. Participants in the workshop were chosen based on their expertise and ability to make changes to design practice or policy. The recommendations include improve pedestrian visibility and illumination at intersections and near crossing locations, eliminating permissive left-turns and slowing down vehicles making left-turn maneuvers, and shortening crossing distances by installing median islands and curb extensions thus reducing pedestrian exposure.

Although the findings and recommendations in this study were based on Oregon crash data, improving older pedestrian safety is an important issue nationwide in the U.S. Older pedestrians have the highest risk for fatal or serious injuries and the recommendations developed in this study can also be applicable in other areas. Additionally, this study also provides a data-driven framework for states to develop their own recommendations. While the focus on this study was on identifying low-cost systemic treatments, consideration of treatments to address speeding may also be beneficial in improving older pedestrian safety and could be a focus for future work. Further, the crash data analysis was on crash data only. Fusing additional data sources, such as exposure or land-use data, with the crash data may provide additional insights on older pedestrian serious injury crash behavior and can be further investigated in future work.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Chris Monsere, David Hurwitz. data collection: Jason C. Anderson; analysis and interpretation of results: Jason C. Anderson, Sirisha Kothuri, Chris Monsere, David Hurwitz; draft manuscript preparation: Jason C. Anderson, Sirisha Kothuri, Chris Monsere, David Hurwitz. All authors reviewed the results and approved the final version of the manuscript.

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