Are There Visual Consequences due to Greater Hood Heights of Larger Pickup Trucks and SUVs?

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ABSTRACT
The height of hoods on pickups and sport utility vehicles (SUVs) has increased in the last twenty years as consumers demand has shifted toward larger vehicles in the United States. Some current model pickups have hood heights as tall as nearly 5-feet. The ability of drivers to see objects, including pedestrians, in the area occluded by the hood present potential issues like those that resulted in back-up cameras in vehicles today. It could also affect the design of pavement markings at signalized intersections. This research reviewed the hood heights of various vehicles, reviewed literature on the topic of hood heights, conducted field studies of a driver's visibility of pedestrians for various combinations of hood height, driver height, advance stop line position and pedestrian location at a signalized intersection, reviewed MUTCD background related to advance stop line use and provides a case study of advance stop line placement in a city in Colorado. The field study created a "visibility index" to compare various scenarios and suggests the visibility of pedestrians by drivers is affected by hood height, windshield area design (large rearview mirror/sensor packages), driver height, and vehicle stopping position (close to crosswalk). Higher hood heights result in roughly a one percent loss in visibility index per increased inch of hood height. With no advance stop line, high hood height vehicles have the potential to fully obscure the visibility of a pedestrian. Setting-back the stop line improves visibility index, but after 4-feet of setback, the improvement in visibility index is much less meaningful.

Keywords: Hood Height, Forward Blind Zones, Driver Visibility, Pedestrian Visibility

INTRODUCTION

Consumers' preferences in the United States for vehicles have changed as the demand for pickup trucks and sport utility vehicles (SUVs) has grown *(1A)*. Beyond consumer preference, financial considerations have also contributed to this change (greater profit margins on trucks and SUVs plus reduced fuel emissions requirements). The number of sedans has been declining and eight of the top ten vehicle purchases in the past year are now pickup trucks or SUVs (*1*), as noted in bold in **Table 1**.

TABLE 1 Top 25 Selling Vehicle Models in the United States

1. Ford F-Series Pickups	**9. Nissan Rogue**	**18. Subaru Crosstrek**
2. Chevy Silverado Series Pickups	10. Honda Civic	**19. Subaru Forester**
3. Toyota RAV4	11. Toyota Corolla	**20. Toyota Highlander**
4. Tesla Model Y	**12. Jeep Grand Cherokee**	**21. Subaru Outback**
5. Honda CR-V	**13. Chevy Equinox**	22. Honda Accord
6. RAM Series Pickups	**14. Hyundai Tucson**	**23. Kia Sportage**
7. GMC Sierra Series Pickups	**15. Chevy Trax**	**24. Toyota Tundra**
8. Toyota Camry	**16. Ford Explorer**	25. Nissan Sentra
	17. Toyota Tacoma	

This is reflected in the percentage of small passenger car sales in the United States which is at or near all-time lows (*2*) (**Figure 1**). At the same time light truck (pickup and SUV) sales are at their peak (Figure 1A).

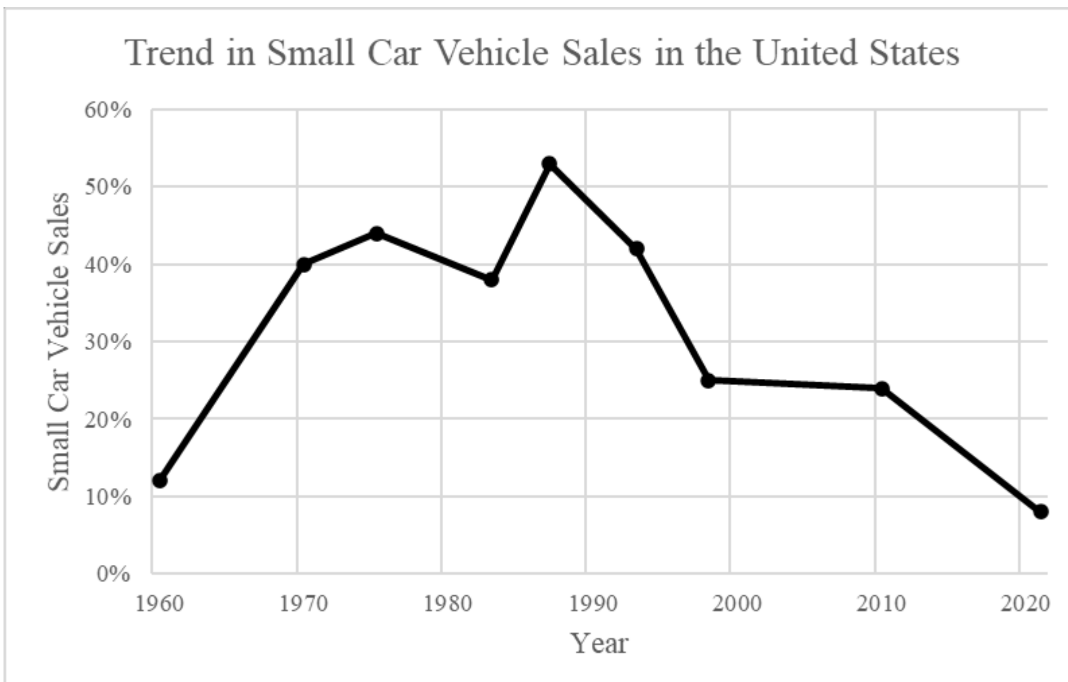


Figure 1 Percentage of Small Vehicles Sold in the United States (*2*)

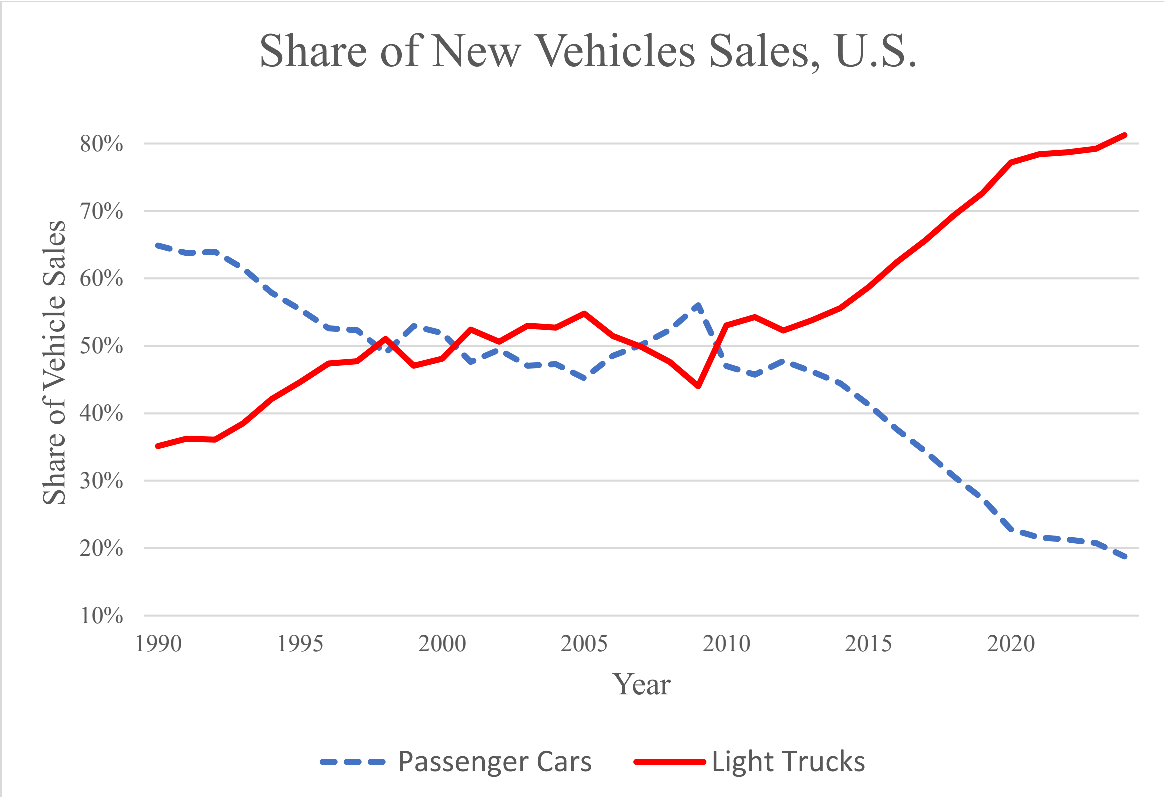


Figure 1A Percent of New Vehicle Sales in the United States (*1A*)

With this shift in the vehicle fleet there has also been an increase in the vertical dimensions of the vehicle hood. Anecdotally this consumer desire has been associated with a perceived sense of safety and security from greater forward visibility of being seated higher, safety of a larger vehicle to the driver/occupants and a lifestyle (towing, loads, clearance) demanding larger vehicles. Hood heights have increased in response to the larger vehicles and their need for larger grills to support engine cooling. The common range of 30 to 50 inches is now approaching as high as 60 inches for some models. Consumer Reports analysis of industry data shows hood heights of pickups have increase 11 percent since 2000 (*2A*). A comparison of hood heights for various popular pickup trucks, SUVs and sedans has been provided (**Table 2**).. Interesting hood height examples include the Ford F250 increasing from 44 inches in 1997 to 52.5 inches in 2024. Even the Honda CRV from 2009 to 2023 saw a hood height increase from 36 to 39 inches in just over a decade.

TABLE 2 Hood Heights of Various Pickups, SUVs, and Sedans

Vehicle (*Pickup Trucks*)	**Hood – center (in)**	**Hood – right fender (in)**
Chevrolet		
2024 Silverado 3500 SWR Crew LTZ	56	54
2024 Silverado Crew LT Trailboss	51/53	51.5
2024 Silverado Crew High Country	50.5	50.5
2024 Silverado 1500 Crew LTZ	50	50
Chrysler		
2024 RAM 2500 Power Wagon Crew Cab	56.5/58	52
2024 RAM 1500 Laramie Crew Cab	49	45.5
Ford		

2024 F350 SRW Crew Cab Lariat	54	53
2024 F250 Super Duty SRW Super Cab	52.5	51
2023 F150 Lightening	49.5	49
2020 Ranger XLT	47	48
2018 F150 XL	47	46.5
1997 F250	44	44
GMC		
2024 Sierra 2500 Crew Cab AT4X	59	55
2024 Sierra 3500 Crew Denali	56	53
2023 Canyon AT4 Crew Cab	49.5	47.5
Honda		
2023 Ridgeline Sport	44.5	44
2023 Ridgeline ED	44	44
Toyota		
2024 Tundra HV 4x4	50.5	51.5
2023 Tacoma TRD	46	45.5
2012 Tacoma	46	44
Vehicle (*SUVs*)	**Hood – center (in)**	**Hood – right fender (in)**
Chevrolet		
2021 Suburban LT	48	49.5
2024 Tahoe LS	49	48.5
2024 Equinox LS	38	39
2024 TRAX Activ	38	38.5
Chrysler		
2024 Jeep Wrangler 4-door Sport	45	44
2024 Jeep Cherokee Altitude X	45.5	44.5
2024 Jeep Cherokee 4XE Anniversary	44.5	44
2023 Pacifica Touring (van)	37	36.5
Ford		
2024 Bronco	49	50
2024 Bronco Sport Big Bend	45	44.5
2021 Bronco Sport Outer Banks	43	43
2024 Explorer	43.5	44
2023 Escape ST Elite	37	37.5
GMC		
2024 Cadillac Escalade ESV	50	49.5
2024 Yukon XL Denali	50	49
2021 Yukon XL SLT	49.5	48.5
2024 Buick Encore GX Sport Touring	40	38.5
2024 Buick Envista Sport Touring	38	37
Honda		
2012 Pilot Touring	43	43
2024 CR-V	38	39
2018 CR-V	38	39
Toyota		
2024 4-Runner	50	50
2024 Highlander Platinum	41	41.5
2024 RAV 4 Prime	39.5	40.5
2023 BZ4X Limited (EV)	36	38

Other Vehicles (*Sedans*)	Hood – center (in)	Hood – right fender (in)
2019 Maserati Ghibli	33	31
2022 Tesla Y	32	33
2024 Honda Civic Sport	32.5	33.5
2024 Toyota Cambry XLE	32	33
2024 Toyota Prius Prime XLE	32	32
2024 Toyota Corolla Hybrid	31	31

NOTES: Measurements conducted February 4, 2024 by Randy McCourt at various dealerships in Beaverton, Oregon.
Hood measurements are from the ground to the point on the hood where the steering wheel is visible (estimated driver eye).
Hood center measurement was taken at the center of the vehicle hood for forward visibility. The right fender measurement was taken at the right corner of the hood as this affects pedestrian visibility toward the sidewalk (hood designs vary vehicle to vehicle). It should be noted that most models the right corner is less than or equal to the center measurement. Some models raise this area for style, appearance and/or panel vibration reduction/stiffening.
Accuracy +/- 1-2 inches

Increasing hood height creates a blind spot in front of the vehicle that can occlude parts of or entire pedestrians (**Figure 2**). A child (commonly 3 to 5-feet tall) would not be visible up to six feet in front of the vehicle. By comparison an average male is about 5-foot, 9-inches (69 inches), an average female is about 5-foot, 4 inches (64 inches). The impact area where the vehicle would strike a pedestrian for the tall pickup is shown in red, while the average sedan impact area is in gold. The blind spot for the tall pickup is shown in gray. A larger pick-up truck hood is nearly higher than a person in a wheelchair (**Figure 3**).

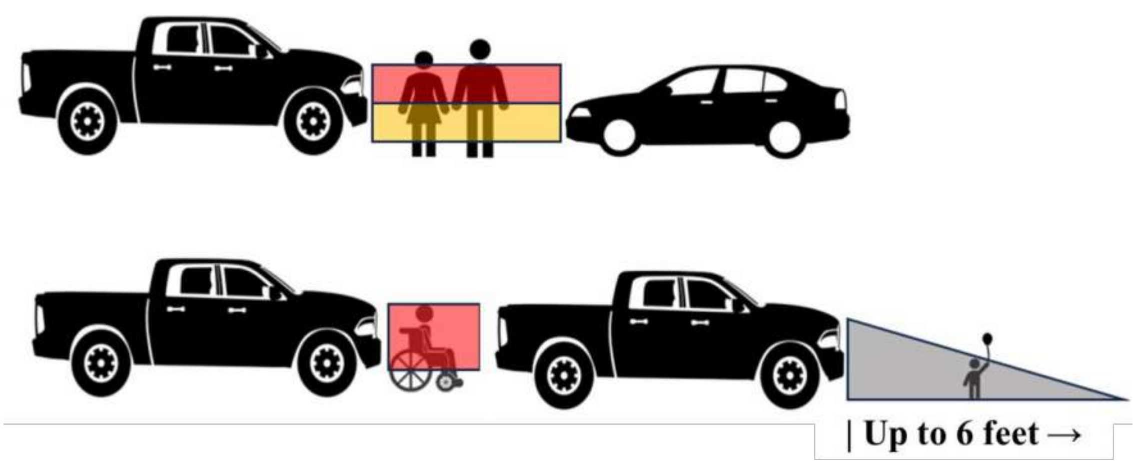


Figure 2 Relationship Between Hood Heights and Average Pedestrians

Figure 3 Pickup Hood Height in Comparison to a Person in a Wheelchair

The objective of this study was to quantify the possible impacts of higher hood height pickups and SUVs on pedestrian visibility at intersections. It includes a review of research related to driver visibility and hood heights, a field study of driver visibility conducted in Corvallis, Oregon, review of the Manual on Uniform Traffic Control Devices (MUTCD) guidance related to advance stop line placement, a case study from Lakewood, Colorado where stop lines were set back from the crosswalk, and the documentation of further research needs.

LITERATURE REVIEW

There were no studies found that evaluated the vehicle stopping position at intersections as a factor for influencing forward visibility. Scholarly literature, such as TRIS/TRID, Web of Science, and Google Scholar, were reviewed to identify studies related to increasing vehicle hood heights. Search terms included but were not limited to: "hood height", "forward blind zones", "driver visibility", "trucks", and "SUVs". Most existing research examines the relationship between hood height and pedestrian injury severity, especially on the impact location and transfer of kinetic energy. There is little current research that examines how hood height affects a driver's forward visibility and their ability to see pedestrians. The literature review in this paper summarizes the key findings from the limited research conducted in this specific area.

Recent research has confirmed that the height and shape of vehicle front ends influences the severity of pedestrian injuries in crashes. One study analyzing police-reported crash data from seven states in the United States (U.S.) showed that vehicles in crashes with tall and blunt, tall and sloped, and medium-height and blunt front-end profiles are associated with higher pedestrian fatality rates than vehicles with low and sloped designs (*3-4*) (**Figure 4**). Interestingly, a relatively flat hood was also found to significantly increase the pedestrian fatality risk. Earlier work reported similar findings by analyzing 82 single-vehicle crashes and finding that SUVs were disproportionately more prone to injuring or killing a pedestrian in a crash, in comparison to passenger cars (*5*). The data suggest injuries from SUV crashes with pedestrians are caused by impacts with the vehicles' leading edge: the bumper, grille, and headlights.

The situation where SUV crashes result in disproportionate injuries and fatalities compared to cars primarily were for crashes of intermediate speed.

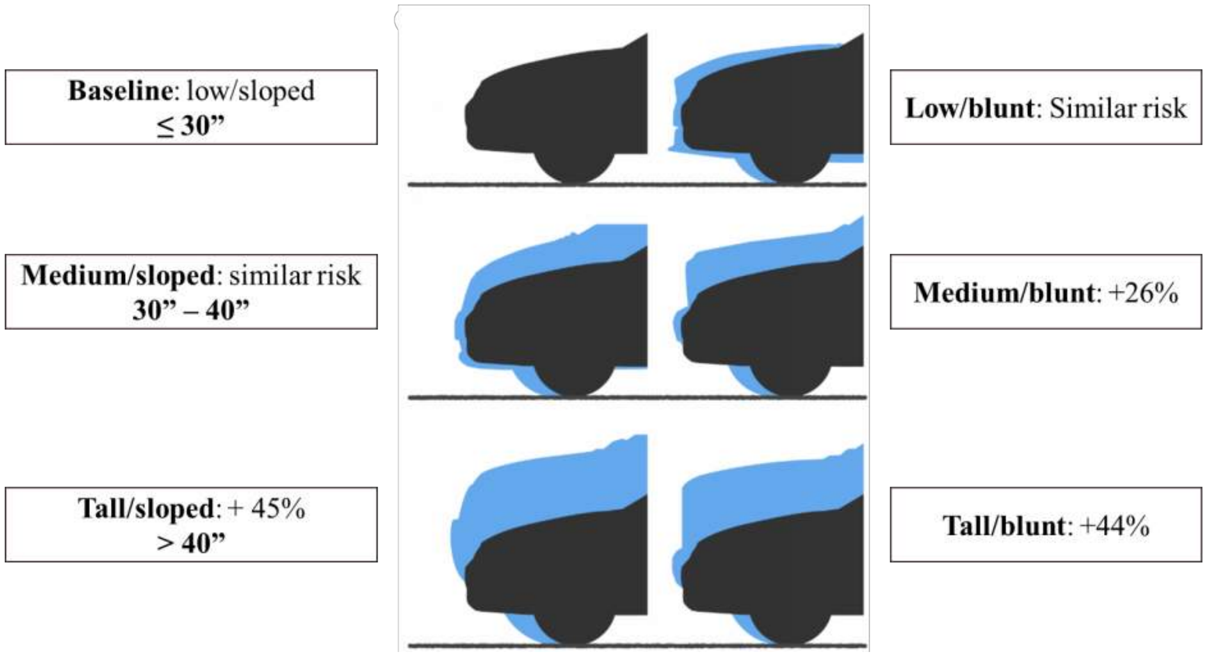


Figure 4 Comparative Risk of Pedestrian Fatality by Hood Leading Edge Height and Shape (*4*)

Matching national crash data with vehicle dimension information, one study found that increasing the front-end height by four inches leads to a 22% increase in the likelihood of a pedestrian fatality (*6*). The study’s author estimated that capping the vehicle front end height at 49 inches could potentially prevent over 500 annual pedestrian deaths in the United States. The author also completed a complementary analysis finding that the widespread replacement of sedans with light trucks that occurred between 2000 and 2019 was associated with over 8,000 additional pedestrian deaths (*7*).

A smaller body of research has focused on how differing vehicle designs impact a driver’s forward visibility and their ability to see pedestrians and prevent crashes. One study created a method for mapping forward blind zones based on the driver’s eye position and hood height of the vehicle (*8*). The findings revealed that driver’s with a direct line of sight react about 0.7 seconds faster and can respond to objects up to 50% more quickly in comparison to those relying on indirect vision. These conclusions are backed by simulator-based studies as well. One study comparing “high-vision” truck cabs, commonly found in the UK, to conventional “low-vision” cabs found in the US, found that drivers in the high-vision designs were significantly less likely to crash with crossing pedestrians (*9*). The same study also found that drivers in the low-vision cabs who relied on crossover mirrors were nine times more likely to fail at detecting a pedestrian directly in front of their vehicle at an intersection. Although mirrors provide some additional visibility, they also create new blind spots and increase the driver’s perception and response times, especially when the vehicle is stopped.

The Boston Blind Zone Safety Initiative conducted field observations of large vehicles that further support these findings. Through documenting visibility conditions around a variety of heavy vehicle types, they found that 87% of fatal bicycle crashes occurred at the front, front-end, or rear-right quadrants of the vehicle which are areas where direct visibility is often limited (*10*).

Despite the growing body of evidence, current U.S. pedestrian safety guidance has not kept pace with the vehicle design trends. National Cooperative Highway Research Program (NCHRP) Report 500 Volume 10 has recommendations for improving pedestrian visibility at crossings, however these improvements only focus on infrastructure treatments such as lighting, signage, and pavement markings.

The report does not mention vehicle size or hood height as an influence on pedestrian visibility (*11*). Given this gap, a recent Transportation Research Board workshop called for a more integrated approach that factors in vehicle size and mass in unison with roadway design, crash outcomes, and policy development (*12*).

The recent update to highway and street design vehicles (NCHRP Report 1061) focuses upon vehicle length, vehicle height, turning characteristics, ground clearance, vehicle types and weight limits. The research focuses on American Association of State Highway and Transportation Officials (AASHTO) green book changes and notes that vehicles classes have become larger and the growing share of light trucks in the vehicle fleet. It does not address hood heights (*12A*).

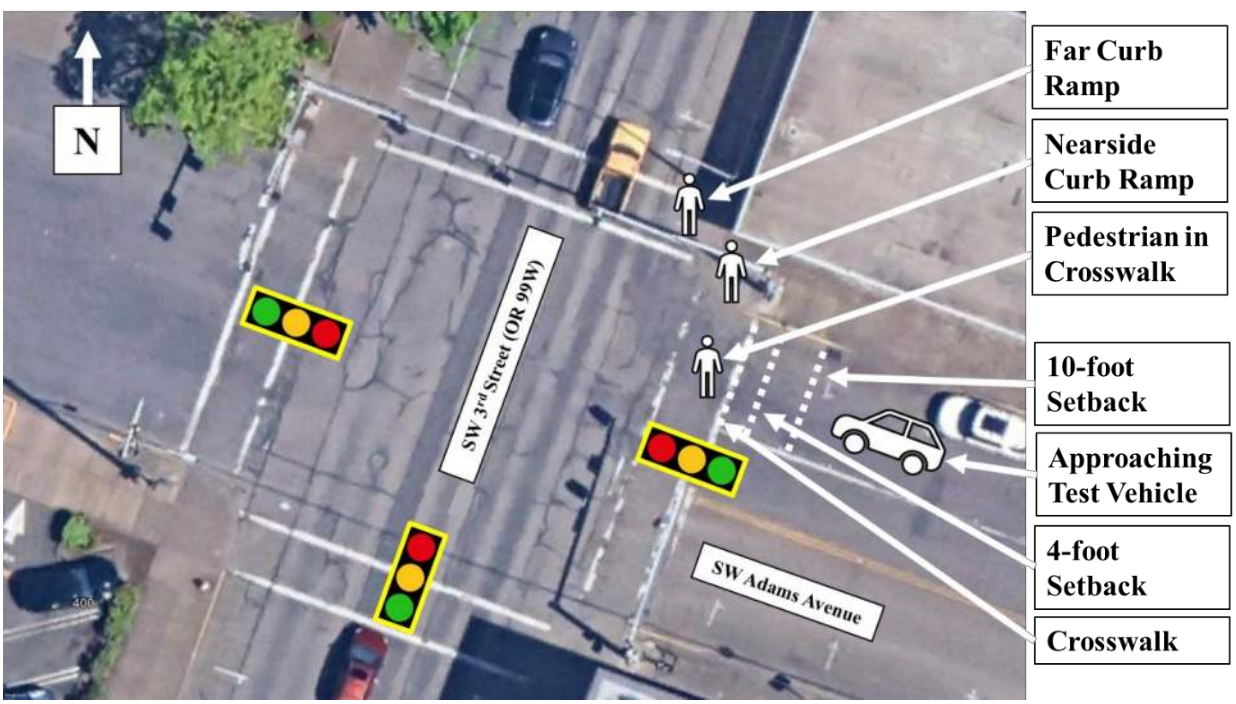
There is still little research directly analyzing driver forward visibility on pedestrian recognition. Furthermore, none of the studies identified in this review factor in the influence of the stopped vehicle's position at an intersection in pedestrian visibility. It is at this point where pedestrians may come into conflict when vehicles turn or proceed into a controlled intersection. This research seeks to advance understanding in this area and offers a practical strategy to improve pedestrian safety at signalized intersections.

METHODS

A quick response research effort was developed to inventory the drivers' visual perspective given various hood heights, driver heights, stop line positions and pedestrian positions.

Study Site

The study effort was conducted in Corvallis, Oregon at the signalized intersection of SW 3rd Street (OR 99W) and SW Adams Avenue (**Figure 5**). Observations were conducted on the west leg (SW Adams Avenue). OR 99W is one way (going northeast) with a posted 25 mph and the location is in a business district which has a statutory speed limit of 20 mph. The traffic signal is 2-phase, fixed time with a cycle length of 75 seconds. The intersection has transverse line crosswalk markings with no advance stop line. The crosswalk is 11 feet wide, and the crossing distance (curb-to-curb) is 52 feet.



Source base aerial: Google Map

Figure 5 Aerial View of Test Site

Field Conditions and Variables

Field work was conducted on two dates: an initial site visit on March 13, 2024, and full data collection on August 14, 2024. The March visit served as a pilot test to assess the feasibility of the study design, verify the suitability of the site, and refine data collection procedures. During this visit, 60 practice observations were conducted, which provided valuable insight into the logistics of the study and how the full data analysis would operate in August. Both March and August observations were conducted under daylight, dry conditions during midday hours. A set of vehicles, drivers, pedestrian positions and vehicle positions were established at the field site (**Table 3**). The driver and positioned pedestrians were part of the study team. The westbound approach right turn lane was used to position the vehicles at the study site's signalized intersection.

TABLE 3 Field Variables for Testing

Vehicle / Hood Height	Driver Height (inches)	Pedestrian Positions	Vehicle Positions
2018 Honda CRV / 38 inches	71	Crosswalk	Zero Setback
2022 Ford Maverick pickup / 41 inches	68	Nearside Curb Ramp	Crosswalk
2018 Ford F250 pickup / 52 inches	60	Far Curb Ramp	4-foot Setback
			10-foot Setback

Driver and Vehicle Positioning

Each driver was told to adjust the position of the seat where they would be comfortable driving and placed the vehicle at different positions (**Table 4**). This always resulted in the vehicle being positioned where the bumper was setback from the crosswalk line. The eye position relative to the stop line was about 2-feet greater for the F250 than the other two vehicles. For the zero-setback vehicle position, the bumper of the vehicle was manually placed adjacent to the approach edge of the crosswalk line. For the other three vehicle positions, the driver was told to stop where they deemed appropriate, which was commonly 2 to 5 feet behind the actual setback line (**Figure 4**). Of note, each of the drivers were hesitant and stopped several times before reaching the actual crosswalk line point for the zero-setback position, as from their perspective, they felt as if they were encroaching upon the crosswalk.

TABLE 4 Horizontal Position of Driver's Eyes and Bumper to Stop Line

	Distance from Crosswalk Line Given Various Vehicle Positions			
Eye Distance to Stop Line	**Zero Setback**	**Crosswalk Stop Line**	**4' Setback**	**10' Setback**
Honda CRV	7'4"	10'9"	10'3"	9'6"
Ford Maverick Pickup	7'6"	11'3"	10'10"	10'8"
Ford F250 Pickup	8'6"	13'4"	12'5"	12'0"
Bumper Distance to Line				
Honda CRV	0	3'3"	2'8"	2'0"
Ford Maverick Pickup	0	3'8"	3'4"	3'0"
Ford F250 Pickup	0	5'0"	4'0"	4'0"

Figure 6 In-Situ View of Test Site

Eye Height of Image Capture

The drivers then held an iPhone 13 mini at eye position and took photos for various scenarios of vehicle type, pedestrian placement, stop line position and driver height. Checks were done to validate that the image view of the camera position reflected the general visibility of the driver at the intersection. Vertical measurements were taken of the eye height of each of the drivers in each of the vehicles after they adjusted seat position (**Table 5**).

TABLE 5 Eye Height for Each Test Driver and Variable

	Driver 1 (Shorter)	Driver 2 (Average)	Driver 3 (Taller)
Honda CRV	52.0	52.0	52.5
Ford Maverick Pickup	51.5	53.0	53.0
Ford F250 Pickup	64.0	65.0	66.5

Measurements were also taken of the person seated in the wheelchair from the pavement to the top of their head. For the people in the group this dimension varied from a low of 48-inches for the shortest person to a high of 51-inches for the tallest person. Eighteen of the vehicles noted in **Table 2** exceed 48-inches of hood height (many of the pickups and a few of the larger SUVs).

Visibility Image Matrix

A series of visibility matrices were created to organize the images that were obtained to compare pedestrian visibility for each driver in each vehicle type at each stop line configuration and for each pedestrian position at the intersection. A sample matrix with the corresponding images is provided to show a few examples of the experimental variables used in the study (**Figure 7**).

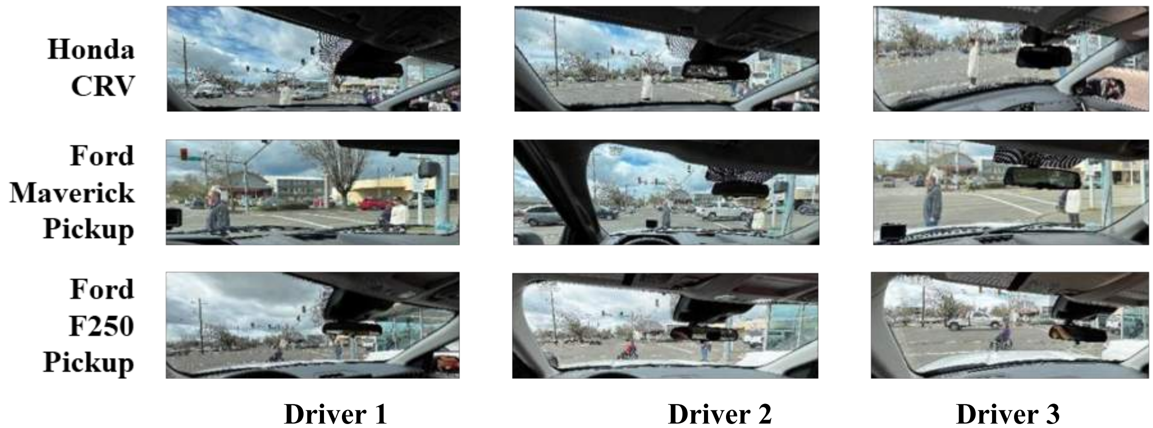


Figure 7 Sample Image Matrix

From these matrices, the driver's view as captured in each picture image of each pedestrian position was analyzed independently by two researchers and grouped into six view categories. Each category was assigned a numeric rating by the researchers. The image and description of the pedestrian visibility categories were standardized (**Figure 8**). A matrix for each vehicle stop position was created. Within each image there were three pedestrian positions visible. This created a matrix for each stop line condition with 54 visibility rating entries. The inter-rater reliability measure between the two raters was 90%, indicating that they exactly agreed on 195 of the 216 unique scenario's ratings. All discrepancies were then resolved through both researchers jointly reviewing the images and agreeing on the final rating.

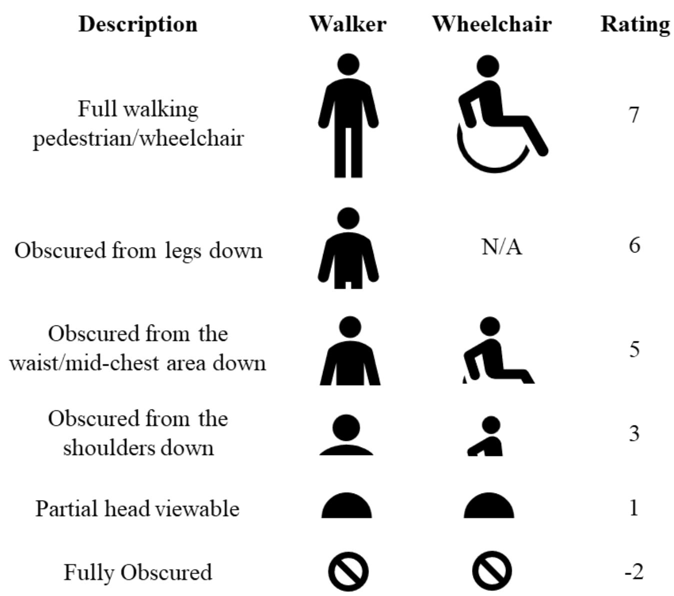


Figure 8 Pedestrian Visibility Categories

RESULTS

An important note during the data analysis was that driver visibility was sometimes partially or significantly obstructed by the rearview mirror or sensor assembly in certain scenarios. Also, pedestrians standing at the nearside curb ramp occasionally partially or fully blocked the view of pedestrians at the far curb ramp. To account for this, the pedestrian visibility categories were adjusted by decreasing their score given how much of the pedestrian was obstructed. Additionally, obstruction-related data was removed from analysis to focus primarily on the impact of the variables of interest. The difference between average visibility index ratings for all the data versus the obstruction removed data is noted in the tables by the increase percentage.

Groups of pedestrian visibility ratings were averaged to compare various scenarios (such as driver height or stop line position) creating a visibility index (**Table 6**). The number of data points represented in the visibility index are highlighted within parenthesis. Comparing various driver heights, the visibility index was mostly unchanged. However, comparing vehicle stopping positions it was found that visibility index improved as the stopping position of the vehicle moved back from the crosswalk line (**Figure 9**).

TABLE 6 Average Visibility Index for Driver Height and Vehicle Position

Driver Height	Visibility Index Rating			Vehicle Stopped Position	Visibility Index Rating		
	All Data	Obstruction Data Removed	Increase (%)		All Data	Obstruction Data Removed	Increase (%)
Shorter	5.3 (72)	6.3 (62)	19	**Zero Setback**	2.8 (54)	5.2 (34)	86
Average	5.4 (72)	6.3 (63)	17	**Crosswalk**	5.3 (54)	6.0 (43)	13
Taller	5.2 (72)	6.2 (44)	19	**4-foot Setback**	6.4 (54)	6.7 (46)	5
				10-foot Setback	6.7 (54)	7.0 (46)	4

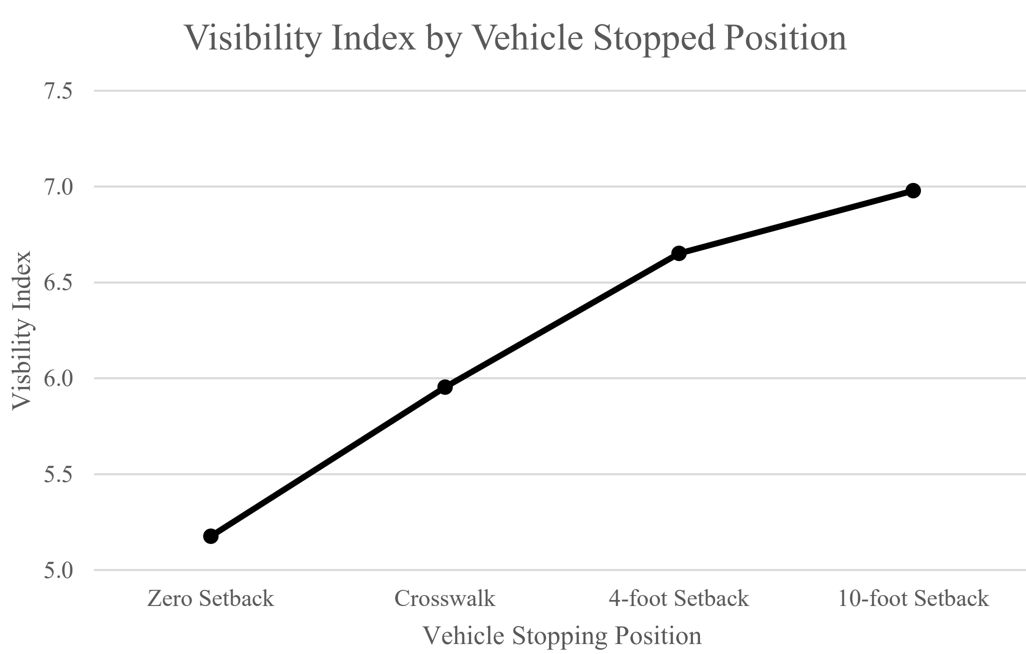


Figure 9 Average Visibility Index by Vehicle Stopped Position

View obstructions (particularly the rear-view mirror/sensor package) had a significant effect on some of the ratings. To address this the data set was analyzed separately with the view obstructed data points removed. This allows for a direct comparison between the different stopping positions of the vehicle, and the subsequent visibility of the pedestrian. The general findings stayed the same (little variance due to driver height, greater variation due to stop-line position); however, the variation in index rating lessened between positions with the obstruction data removed.

A separate visibility index analysis was done to assess hood height (**Table 7**). The analysis is again given for the entire dataset, as well as the dataset where view obstructions were removed. The percentage increase of the index rating for the full dataset to the dataset where obstructions were removed is also included. The full dataset visibility index ratings provide confounding results due to the significant impact of view obstructions caused by rearview mirrors/sensor placement in the windshield area and the position of the pedestrians at street corners. With the obstruction data removed the visibility index decreases with hood height (**Figure 10**).

TABLE 7 Average Visibility Index for Vehicle Types (Hood Height)

Vehicle Type	Hood Height (inches)	Visibility Index Rating		
		All Data	Obstruction Data Removed	Increase (%)
Honda CRV	38.0	5.1 (72)	6.6 (48)	29
Ford Maverick Pickup	41.0	5.5 (72)	6.4 (55)	16
F250 Pickup	52.0	5.3 (72)	5.9 (66)	11

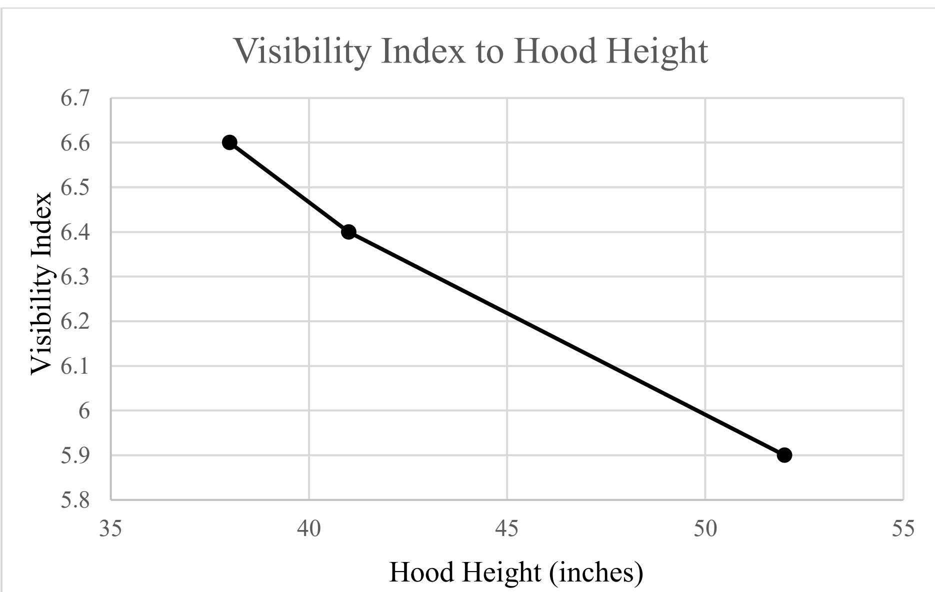


Figure 10 Average Visibility Index by Hood Height

Analysis of pedestrian and wheelchair position was also conducted (**Table 8)**. The far curb ramp position was most affected by view obstructions. Without obstruction data (which isolates the effect of hood height), the far curb ramp position has the highest visibility index. The crosswalk pedestrian and wheelchair position is most affected by hood height. Including the obstruction data, the far curb ramp pedestrian and wheelchair positions are the worst. Pedestrians in the crosswalk were not impacted by view obstructions as they are straight in front of the driver's line of sight. There was a 15-40 percent% reduction in data for the near side and far side crosswalk pedestrian positions, respectively, for factors not related to hood height. Walking pedestrians have a higher visibility index than wheelchairs by about eight percent%.

TABLE 8 Average Visibility Index for Pedestrian Position at the Intersection

Pedestrian Position	Walker			Wheelchair		
	All Data	Obstruction Data Removed	Increase (%)	All Data	Obstruction Data Removed	Increase (%)
Crosswalk	6.1 (47)	6.1 (36)	0	5.1 (36)	5.1 (36)	0
Nearside Curb Ramp	6.4 (36)	6.6 (27)	3	6.4 (36)	6.6 (31)	3
Far Curb Ramp	4.0 (36)	7.0 (20)	75	3.9 (36)	7.0 (19)	79

That said, to better understand the data and account for all the variables at once, a series of statistical analyses was performed. However, before that, a machine learning technique was applied to assess the importance of the variables and their levels. The dependent variable was the visibility index score, while the independent variables included driver height with three levels (60, 68, and 71 inches), pedestrian type (walker and wheelchair), hood height (38, 41, and 52 inches), vehicle position relative to the crosswalk (zero setback, before the crosswalk, 4-foot setback, and 10-foot setback), and finally, pedestrian position with three levels (at the crosswalk, nearside curb ramp, far curb ramp). That is a total of five factors with fifteen levels in total.

To sort out the importance of each variable to the overall model and to avoid overfitting, a random forest analysis with a permutation technique (repeated 100 times) was conducted on the data. This technique helped reduce the influence of variables that contribute to overfitting in the test dataset. If the drop in accuracy score was above zero for a specific input variable, it indicated that the model was more sensitive to that variable and that it should be kept. In contrast, a negative or zero score implied that the model's performance remained the same even when there were changes in that variable.

From the empirical correlations, the permutation importance of each input variable was evaluated in relation to predicting the visibility index score (the higher the better). The results of the random forest analysis (15 levels) are shown in Figure 11. As seen in the figure, visibility was most sensitive to changes in pedestrian at crosswalk and vehicle positions with zero setback, followed by taller hood height and pedestrian type. Driver height showed the least influence, with a score below zero.

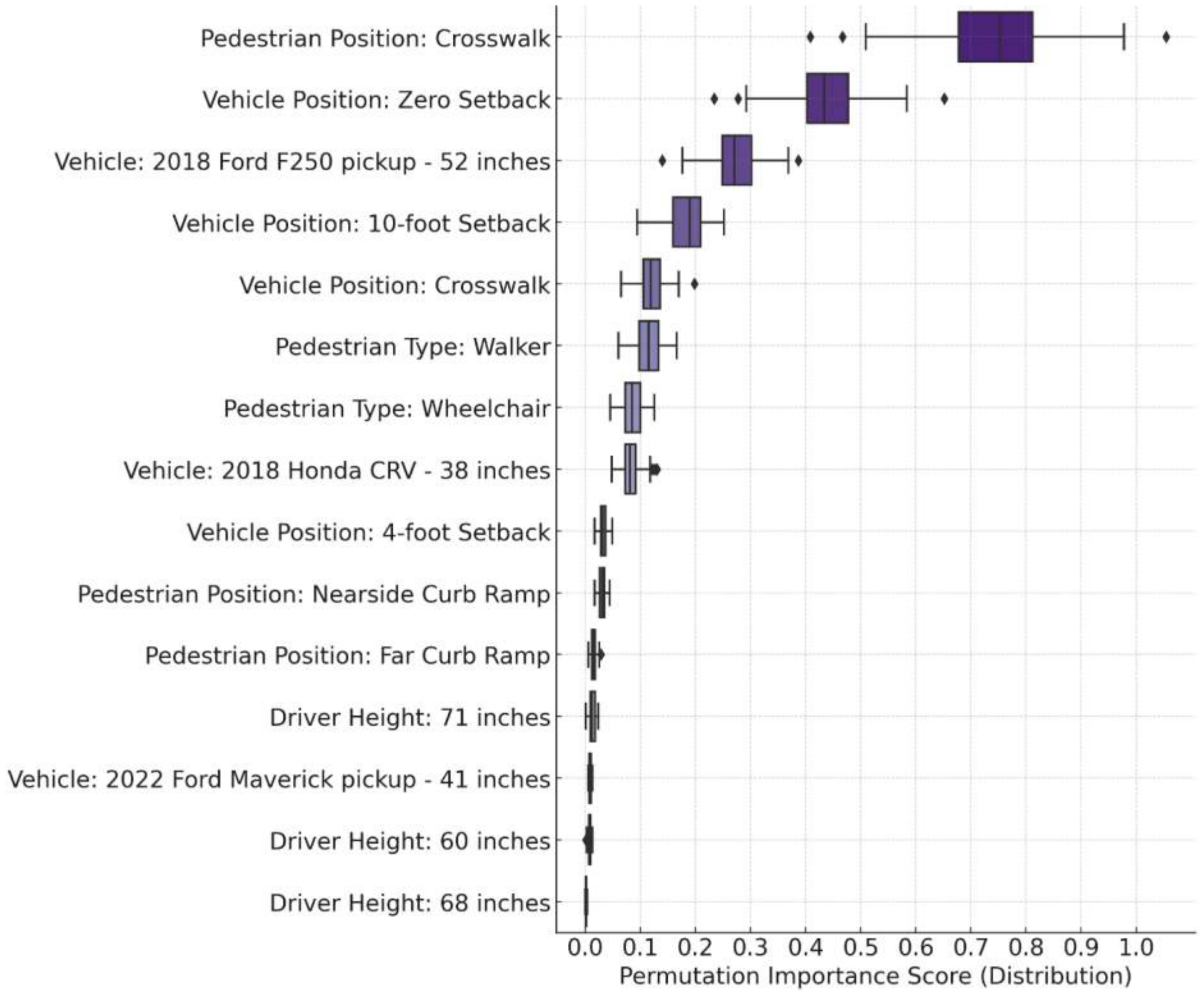


Figure 11 Random Forest Model Sensitivity Analysis (by importance)

Following the random forest technique, a linear mixed model was initially developed to account for the random effect introduced by driver height, since each driver completed multiple runs. However, because the random effect was not statistically significant, a general linear model was conducted treating driver height as a fixed effect in addition to other variables (**Table 9**). Building on the variable importance results from the random forest variables selection technique, the regression model showed consistent trends. To that end, all variables were statistically significant (p-value < 0.01) compared to their baselines, except for drivers with a height of 68 inches, which showed an approximately similar visibility index to 60 inches (p = 0.64), and the Ford Maverick (41 inches) when compared to the 38-inch Honda CRV (p = 0.14). Even though the 68-inch driver height was not statistically significant, it still showed a positive relationship compared to the 60-inch baseline. Similarly, while the Maverick was not significant at the 95% confidence level, its p-value falls within an 84 percent confidence interval (CI), and the negative coefficient suggests a decline in visibility when compared to the Honda vehicle.

TABLE 9 Regression model outputs of the Visibility Index

Variable	Coefficients	SE	T-Value	P-Value
Constant	5.10	0.21	24.73	0.00*
Driver Height				
60 inches	*Baseline*			

68 inches	0.07	0.14	0.47	0.64
71 inches	0.35	0.16	2.21	0.03*
Pedestrian Type				
Walker	*Baseline*			
Wheelchair	-0.45	0.12	-3.74	0.00*
Vehicle - Hood Height				
2018 Honda CRV - 38 inches	*Baseline*			
2022 Ford Maverick pickup - 41 inches	-0.23	0.16	-1.47	0.14
2018 Ford F250 pickup - 52 inches	-0.85	0.15	-5.56	0.00*
Vehicle Positions				
Zero Setback	*Baseline*			
Crosswalk	0.70	0.19	3.75	0.00*
4-foot Setback	1.35	0.19	7.29	0.00*
10-foot Setback	1.67	0.19	9.05	0.00*
Pedestrian Positions				
Crosswalk	*Baseline*			
Nearside Curb Ramp	1.19	0.14	8.41	0.00*
Far Curb Ramp	1.21	0.16	7.36	0.00*

**Statistically significant at the 0.01 level*
Coefficient refers to the linear equation coefficient from regression analysis
SE is standard error
T-Value is the ratio of the difference in a number's estimated value from its assumed value to its standard error

DISCUSSION

Among the various factors, vehicle stopping position had the most significant effect on visibility index. As shown in **Figure 9** and **Table 6**, visibility index scores improved substantially as the vehicle was positioned farther from the crosswalk. The zero-setback position produced the lowest visibility score, while the 10-foot setback position had an average visibility index rating of 7.0, representing full visibility of the pedestrian. Notably, visibility index rating improvements diminish between the 4-foot and 10-foot setback positions, suggesting that a 4-foot stop line setback may be a practical threshold for achieving meaningful visibility gains.

Hood height also played a role in determining pedestrian visibility for the different scenarios presented. While only three hood heights were tested, it appears higher hood heights result in roughly a one percent loss in visibility index per increased inch of hood height. When considering wheelchairs in crosswalks, higher hood height vehicles are associated with much lower visibility index than pedestrians (a visibility index of one for wheelchairs compared to five for pedestrians in the crosswalk with the F-250).

The location of the pedestrian's positioning at the intersection also influenced their visibility to drivers. Pedestrians positioned directly in the crosswalk were consistently the least visible across all vehicle types and stopping positions. In contrast, those positioned at the far curb ramp were always fully visible, unless blocked by a mirror or the other pedestrian. These differences in visibility findings were reflected with an average visibility index rating of 6.1 for walkers and 5.1 for wheelchairs in the crosswalk, versus scores of seven for both walkers and wheelchairs at the far curb ramp. When these obstructed scenarios were not removed from the dataset, the far curb ramp position yielded the lowest visibility index, suggesting that this position might be influenced more by inherent driver blind spots, rather than the hood height or stopping position of the vehicle.

Obstructions caused by non-hood related design elements, such as the rearview mirrors and sensor packages on the windshield or the other pedestrian at the intersection, were found to significantly affect driver visibility. These obstructions were especially problematic when pedestrians were located at the nearside or far curb ramps, as the pedestrian at the nearside curb ramp often partially obstructed their view to the driver. The zero-setback condition was most affected, with visibility index scores increasing by 86 percent after such obstructions were removed. These obstructing features did not disproportionately impact taller drivers, which might have been considered given that their eye positions were more likely to align with the mirror and sensor housing. Instead, the visibility index ratings increased by the same 19 percent for both shorter and taller drivers when the obstruction data was removed, with average driver height only seeing an increase of 17% for their average visibility index rating.

Driver height had little variation in visibility index rating whether or not obstructions were considered. Drivers produced about the same visibility index ratings after being told to adjust their seats to a comfortable driving position. Vertical eye height measurements (**Table 4**) confirmed that drivers naturally positioned themselves at roughly the same height in the vehicle. This finding indicates that differences in visibility were not due to driver height and instead were primarily due to the other factors being studied.

When analyzed together, these results emphasize the importance of vehicle design and design characteristics of intersections for pedestrian safety. Specifically, considering a 4-foot stop line setback could significantly improve pedestrian visibility at intersections, particularly given the ongoing trend of increasing hood heights in modern vehicle designs.

Past Applications of Advanced Stop Lines

The Manual on Uniform Traffic Control Devices (MUTCD) includes the application of a 4-foot advance stop line to a crosswalk as a guidance (*13*). Guidance refers to a statement of recommended practice in typical situations, with deviations allowed if engineering judgment or engineering study indicates the deviation to be appropriate. It has been a part of the MUTCD since 1948. More recently use of advanced stop lines has become a common means of providing space for bicyclists (bike box) at busy urban intersections to allow cyclists to be positioned ahead of other traffic.

Past Federal Highway Administration (FHWA) studies indicated that marked crosswalks alone are insufficient in situations where speed limits exceed 40 mph, roadways with four or more lanes with or without raised medians where volumes exceed 12,000 and 15,000 respectively (*14 – 15*). This has led some practitioners to consider advance stop lines only with higher speed to avoid possible impacts on lost time for traffic signals due to greater clearance time. However, in this study vehicles were stopped, and the visibility issues were associated with transitions from stopped conditions to moving (such as a right turn on red where the driver looks away from the pedestrian conflict area and then proceeds into space where visibility may be impacted due to hood height). Because of this, the issue of advanced stop lines would not appear to be as associated with speed as intersection visibility.

Case Study: Lakewood, Colorado Experience

The City of Lakewood, Colorado has a pavement management program that repaves and restripes many of their arterial streets. Given the regular snow conditions, striping is re-applied every one to two years. The city had been placing advanced stop lines using the MUTCD minimum setback of 4-feet (no stop lines were use on approaches that were residential streets or roads posted ≤30 mph). In response to a crash investigation, the city began in 2024 and 2025 to place advance stop lines for all signalized intersections. They have been utilizing high visibility longitudinal bars (continental pattern) that are nine feet wide with an eight-foot gap between the crosswalk markings and the stop line. For locations that did not have advance stop lines (typically locations ≤30 mph) they are adding them and for locations that had them four-feet in advance of the crosswalk they moved them back and additional four-feet.

The City used video cameras to observe stopping behavior before and after some of the initial changes from 4-foot to 8-foot in advance of the crosswalk (*16*). Approximately 50 signal cycles were reviewed for each condition, representing about three hours of cumulative signal activity across two days of footage (one before and one after the change using the same time window of 2:00 to 4:00 p.m. on similar days of the week). Observations were conducted by reviewing archived traffic footage at 16x speed. About 65 percent of the drivers did not encroach over the stop line positioned 4-feet in advance of the crosswalk. Line pavement marking conditions were good. With the stop-line move back to 8-feet in advance of the crosswalk about 70 percent of the drivers did not encroach beyond the stop-line. The pavement line marking condition was excellent in this scenario.

Drivers did not change stop position behavior substantially with a change in the position of the stop line between 4 and 8-feet. Casual observations by operations staff and pool drivers indicated that the change was not noticeable relative to their expectations for stopping at a signalized intersection. It found that “concerns” that drivers might violate the stop line at greater frequency if advance stop lines are used (at or beyond 4-feet) was not warranted.

CONCLUSIONS

Consumers in the United States have significantly shifted toward purchasing vehicles with larger hood heights, such as pickup trucks and SUVs, over the past several decades. This has led to many popular vehicles having hood heights greater than 50 inches, contributing to forward visibility issues and reduced pedestrian visibility. This study was developed in response to these trends, with the goal of quantitatively assessing how hood height, vehicle stopping position, pedestrian location at the intersection, and driver eye height affect the driver’s ability to see pedestrians, including pedestrians using wheelchairs. A field study was conducted at a signalized intersection in Corvallis, Oregon using three vehicles with varying hood heights, multiple driver heights, and staged pedestrian positions at the intersection. Observations were then collected at four designated stopping positions: zero setback (front bumper of vehicle on leading edge of crosswalk line), and driver’s natural stopping positions at the crosswalk line, 4-foot setback line, and 10-foot setback line. A visibility index was created based on photographs to quantify pedestrian visibility for each combination of variables.

Results from the study show that the vehicle stopping position had the greatest influence on pedestrian visibility out of the tested variables. Drivers who stopped at the 4-foot or 10-foot setback line consistently had higher visibility scores, while those that were at the zero-setback line had much lower visibility of pedestrians. A relationship was also observed between the increasing hood height of the vehicle and decreasing visibility index scores particularly for wheelchairs in the crosswalk, demonstrating lower forward visibility of higher hood vehicles. Pedestrian location within the intersection also influenced visibility outcomes as pedestrians in the crosswalk were consistently the least visible across all vehicle types and stopping positions. Driver height had little influence on the visibility index scores, as once drivers had adjusted their seats to their natural driving position as they were instructed. The adjustments resulted in their vertical eye heights being nearly the same. Obstructions caused by rearview mirrors or other sensor packages in the windshield, as well as the obstruction that the pedestrian at the nearside curb ramp had on the far curb ramp pedestrian, created additional difficulties for drivers in seeing pedestrians at intersections. These findings support the implementation of advance stop lines, especially at 4-foot setbacks, as a practical countermeasure to improve pedestrian visibility amid the growing presence of higher hood vehicles in the modern vehicle fleet.

Areas for Future Research

Based on the field findings from this study, there are several areas that merit further investigation into the understanding of how vehicle design and roadway features affect pedestrian visibility. The study looked at three hood heights. Additional research is needed on pedestrian visibility for vehicles with hood heights that range between 50 and 60 inches, as these are increasingly becoming common in the vehicle fleet. This research could further the development of a relationship between hood height visibility index to determine if there is a critical hood heigh for visibility. It could also assess shorter hood heights such as sedans. Analyzing windshield design and the cases where space is occupied by large sensor packages potentially obstructing forward vision also merits attention. There is also a gap in exploring the creation of a standardized visibility testing method, such as the visibility index used in this study, for all new vehicle models. A vehicle design area of interest is how taller drivers experience visibility in smaller vehicles, and how this could differ from typical driver-vehicle configurations.

At the intersection level, further research is recommended on how various curb return radii affect pedestrian visibility, as the current study was only conducted with 15-ft curb return radii. There is also a need for a more refined understanding of the advance stop line position in the greater than 4-foot range in relation to safety. Including in this study an analysis on the influence of posted speeds, such as at or above 30 mph in comparison to 25 mph or less, would provide beneficial as well.

Human factors testing of the driver in the vehicle for the purpose of assessing and identify the best, most uniform way(s) to inform drivers of the visibility limitation they experience for is warranted high hood vehicles (>50-inches). This could include visual or auditory warning, dashboard alerts, or forward-facing camera systems that are similar in function to back-up cameras, especially when the vehicle is stopped or travelling at low speeds. These systems should consider the differences in direct and indirect vision to pedestrians and how this influences driver response time.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Randy McCourt, David Hurwitz; data collection: Wyatt Brown, Randy McCourt, David Hurwitz; analysis and interpretation of results: Wyatt Brown, Hisham Jashami, Randy McCourt, David Hurwitz; draft manuscript preparation: Wyatt Brown, Hisham Jashami, Randy McCourt, David Hurwitz. All authors reviewed the results and approved the final version of the manuscript.

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