Evidence of Pedestrian Dilemma Zones at Uncontrolled Crossings

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ABSTRACT
For pedestrians crossing at uncontrolled locations, the pedestrian needs to properly judge the required gap necessary to safely cross all lanes of traffic. This requires the pedestrian to be able to see all the vehicles at enough distance to make the proper decision of when to cross. This can be referred to as pedestrian sight distance (PSD). This PSD is the requirement needed for a pedestrian to be able to view the vehicle at enough distance to safely cross the street. This PSD is only half of the necessary requirement though. There is also a requirement for a driver of a vehicle to be able to see the pedestrian and have the necessary stopping sight distance (SSD) to stop for the pedestrian in the crosswalk in case a pedestrian misjudges the gap or emergently stops while in the crosswalk. In many scenarios, the required SSD can be greater than the available PSD. This creates a dilemma for the pedestrian, where the pedestrian might believe there is an adequate gap, but since the driver cannot see the pedestrian in the required time to stop, that pedestrian is in real danger of getting hit. This paper examines scenarios where this pedestrian dilemma zone occurs. Recognizing that this problem exists can lead to various counter-measures to ensure safe crossings at uncontrolled locations.

INTRODUCTION

Guidance for pedestrian planning and design has been developed over the years by various organizations, such as the American Association of State Highway and Transportation Officials (AASHTO 2011), Federal Highway Administration (2009), Transportation Association of Canada (2007), and New Zealand Transport Agency (2009). The literature is also rich with many studies that have focused on specific elements of pedestrian crossing, such as pedestrian walking speed and start-up time for signalized intersections (Fitzpatrick et al. 2007, Guerrier, et al. 1998, Knoblauch et al. 1995, Coffin and Morrall 1995,). Nonetheless, pedestrian safety continues to be a major issue on transportation facilities in the US. According to the National Highway Traffic Safety Administration (NHTSA 2015), pedestrian fatalities represented 11% of all traffic fatalities in 2005 and in 2014 the share increased to 15%. This means that as total traffic fatalities decrease in the US, pedestrian fatalities are on the rise.

One glaring need to improving pedestrian safety is the need to improve the design and location of “unprotected” pedestrian crossings, where the pedestrian must determine if there is a safe gap in traffic to cross. Currently, there is no guidance in the AASHTO Green Book for the safe design of pedestrian crosswalks. Pedestrian crossings at ramps, unsignalized intersections, and mid-block are sometimes put at locations where the pedestrian cannot safely view the vehicle properly to make a proper judgment of whether it is safe to cross.

Some examples of where this is an issue includes:

- At an intersection where the crosswalk is not placed parallel to the sidewalk and a sign or landscaping blocks the view of potential vehicles turning into the crosswalk.
- A crossing near a horizontal curve and/or a vertical crest curve that prevents the pedestrian from seeing vehicles around the curve/over the hill.
- A crossing with landscaping in the median blocking views.
- A crossing where a platoon of vehicles creates a sight distance issue.

Easa (2016) started to address this concern by developing pedestrian crossing sight distance criteria (PCSD). These criteria examined what the needs are for a pedestrian to see a vehicle at the proper distance to safely judge accepting a gap in traffic to cross. The methodology developed was applicable to all types of pedestrian crossings on straight and curved roadways. This methodology was fairly comprehensive in addressing the requirements needed for a pedestrian seeing a vehicle but did not address the issue of the driver of the vehicle being able to see the pedestrian at the proper distance to stop for the pedestrian in the crosswalk if needed.

However, existing guidance for pedestrian crossings do not address the need for the driver of the major road to stop. There is a need for a driver of a vehicle to be able to see the pedestrian and have the necessary stopping sight distance (SSD) to stop for the pedestrian in the crosswalk in case a pedestrian misjudges the gap or emergently stops while in the crosswalk. In many scenarios, the required SSD can be greater than the available pedestrian sight distance (PSD). This creates a dilemma for the pedestrian, where the pedestrian might believe there is an adequate gap, but since the driver cannot see the pedestrian in the required time to stop, that pedestrian is in real danger of getting hit. This paper examines scenarios where this pedestrian dilemma zone occurs.

The next sections presents the definitions of PSD and SSD, state the preliminary hypothesis, and discuss the relationship between PSD and SSD. The following sections present the evaluated scenarios and the respective results, followed by a discussion and conclusions.

SIGHT DISTANCE ISSUES

Pedestrian Sight Distance

Pedestrian sight distance (PSD) is the distance along the major road that allows a pedestrian to safely cross the major road at a pedestrian crossing or at an uncontrolled intersection with a minor road controlled by a stop sign, as shown in Fig. 1. The time needed for pedestrians to cross the major road is given by

$$T_P = t_p + \frac{D}{V_w} \qquad (1)$$

where
T_T = total pedestrian crossing time (s),
Tp = pedestrian perception-reaction time (s)
D = total crossing distance (ft or m),
V_w = walking speed (ft/s or m/s)

The required pedestrian sight distance along vehicle path on the major road, PSD_r, is then given by

$$PSD_r = 0.278\, V_v\, T_P \quad \text{(metric)} \qquad (2)$$

where
PSD_r = required pedestrian sight distance along the centerline of Lane *i* (m),
V_v = design speed of the major road or the freeway ramp (km/h).

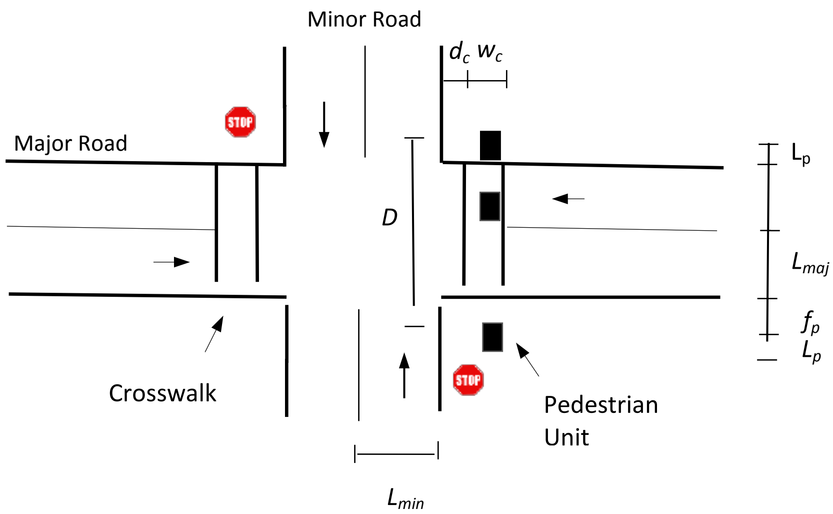

FIGURE 1 Elements of pedestrian sight distance at two-way stop-control intersection (two-lane major road)

Stopping Sight Distance
Stopping sight distance is calculated, based on AASHTO (2011), as follows

$$SSD = 0.278\, V_v\, t_{SSD} + \frac{{V_v}^2}{254(\frac{a}{9.81}+G)} \quad \text{(metric)} \qquad (3)$$

where
t_{SSD} = perception-brake reaction time for the stopping of major-road vehicle (s),
a = deceleration rate (m/s^2) and
G = longitudinal grade of the major road (positive for upgrade and negative for downgrade (percentage / 100).

PRELIMINARY HYPOTHESIS

In order for a pedestrian to cross a roadway safely, the pedestrian needs to be able to view an oncoming vehicle at a far enough distance to determine whether there is an adequate gap to cross. The pedestrian must see the vehicle at an adequate distance, i.e. have adequate pedestrian sight distance (PSD).

But there could be a second side of the equation. Can the driver safely stop for a pedestrian within the crosswalk? In other words, is there adequate stopping sight distance (SSD) for the driver?

The theory is as follows: If the required PSD is greater than the required SSD, the crossing would be considered the safest possible outcome. The reasoning is that while the pedestrian is in the crosswalk, the driver would still have time to stop if needed.

If the required SSD is greater than the required PSD, then the crossing has a potential limited margin for error. It indicates that although the pedestrian has an adequate PSD to cross without getting hit, if the pedestrian slows down or emergently stops while in the crosswalk, the approaching vehicle will not be able to stop in time. This creates a "pedestrian dilemma zone".

It should be noted that there are also more severe pedestrian dilemma zones where the minimal PSD does not exist at the crossing. This can occur at both uncontrolled and controlled crossings and is more common than likely realized. This is the ultimate pedestrian dilemma zone. However, this scenario is beyond the scope of this paper, since this scenario is often solvable by recognizing the problem and simply providing adequate PSD.

FIGURE 2 – Crossing at I-590 / Moana Lane Northbound On-Ramp with PSD and SSD Issues (Reno, Nevada, Photo: Chlewicki)

The hypothesis is that there are certain scenarios where the required SSD will be greater than the available PSD creating pedestrian dilemma zones.

EXAMINING PSD AND SSD

Before evaluating various scenarios, an understanding of both PSD and SSD is needed.

For PSD, the required sight distance is calculated from the point where the pedestrian is standing before making the decision to cross. The calculation includes a perception-reaction time for the pedestrian, where there is a small amount of time before the pedestrian begins the crossing when the pedestrian makes the decision that it is safe to cross and starts crossing. The calculation then determines how long it will take for the pedestrian to cross each lane of traffic with the assumption that the vehicle maintains a constant speed.

For SSD, the required sight distance is calculated at the point where the pedestrian is already in the crosswalk and there might be a need to stop. This means that not only is the SSD a separate distance from the PSD, but there is also a temporal delay from when the PSD is calculated to when the SSD is calculated. This delay increases for each additional lane the pedestrian crosses.

The SSD is then the sum of the perception-reaction time of the driver plus the time it takes the vehicle to decelerate to a stop prior to the crosswalk.

The temporal delay between the start of the PSD calculation and SSD calculation, plus the added perception-reaction time for the driver is what makes it possible for the required SSD to be larger than the available PSD.

There is another element that needs to be considered for sight distance, which is that not all sight distance obstacles are static. There are three obstacle categories to consider in pedestrian sight distance analysis:

1. *Static Obstacles*: These obstacles are relatively permanent, such as trees, road signs, landscaping, and poles.
2. *Semi-Static Obstacles*: When a pedestrian is crossing, the obstacle is relatively static, but the obstacle might not always be there. Parked cars are examples of something that is semi-static. A transit stop for a bus, trolley, or train near the intersection could also be considered semi-static.
3. *Dynamic Obstacles*: Vehicles in motion near the intersection can have a dynamic effect on sight distance. For a two-lane roadway with one lane in each direction, this becomes more of a problem when the near-side vehicles pass the intersection and block the view of the far-side approaching vehicles. If this dynamic obstacle is an issue for the pedestrian to cross, the pedestrian can choose to delay the crossing. However, if a pedestrian chooses to cross at a point where there is no dynamic sight distance issue, it is possible that the far-side approaching vehicle will then have a dynamic SSD issue.

Evaluated Scenarios

This paper focuses on uncontrolled intersections with two-lane major roads and a minor road with stop control

For all scenarios, there are several basic assumptions.

1. The pedestrian has no disabilities and walks at an average speed of 3.5 ft/s (1.1 m/s). The objective of this study to identify minimal criteria where there is going to be a pedestrian dilemma zone issue. If there is an issue for an abled pedestrian, there will definitely be an issue for a disabled pedestrian.
2. Pedestrian perception-reaction time is assumed to be 2 s.
3. Lane width of the major and minor roads is 12 ft (3.75 m) and its longitudinal grade is zero.
4. Length of pedestrian unit is 5 ft (1.5 m) and the offset of the pedestrian unit from the curb is 6 ft (1.8 m).
5. The design values of perception-brake reaction time and deceleration rate are 2.5 s and 11.2 ft/s^2 (3.4 m/s^2), respectively, as recommended by AASHTO (2011).
6. Perception/reaction time for a driver starts once a pedestrian is at the crosswalk and the same travel lane as the vehicle.
7. Each scenario is tested for different traveling speeds. The maximum speed that will be tested will be 50 mph (80 km/h). The minimum speed that will be tested is 25 mph (40 km/h). Speeds will be tested at 5 mph increments.
8. Lane widths will be assumed as 12 feet wide (3.75 m).
9. For this study, only two-lane roadways are being examined with one travel lane in each direction. Multiple lanes in the same direction would obviously add additional issues.

Based on the preceding assumptions, the total pedestrian crossing distance of a two-lane roadway is D = 7.5 + 1.5 + 1.8 = 10.8 m. and the full crossing time is T_p = 1.5 + 10.8 / 1.1 = 11.3 s. Crossing one lane would be 3.75 + 1.5 + 1.8 = 7.05 m and the crossing time is T_p = 1.5 + 7.05 / 1.1 = 7.9 s

Scenario 1 – Ideal, Open Space, Low-Volume Traffic

This scenario looks at the most ideal conditions possible. There are no dynamic SD issues; the roadway is relatively straight horizontally and vertically.

In this scenario, we will make the assumption that the driver can view the pedestrian before the crossing starts and is anticipating a pedestrian crossing. In the ideal condition, this means that there is virtually no temporal delay for the SSD except for the perception/ reaction.

The required PSD to cross the near side would be simply the crossing time multiplied by the speed of the vehicle. The results of the calculation for required PSD and available SSD (rounded up to the nearest 5 ft) are shown in Table 1.

TABLE 1 Comparison of Required SSD and Available PSD for Scenario 1: Open Space, Low-Volume Traffic (Bold numbers indicate SSD > PSD)

Major-Road Speed (mph)	Near-Side PSD (ft)	Far-Side PSD (ft)	SSD (ft)			
			G = 0%	G = -10%	G = -15%	G = -20%
25	305	430	155	175	200	235
30	370	515	200	230	265	315
35	430	605	250	295	335	405
40	490	690	305	365	420	**510**
45	550	775	360	440	505	**625**
50	610	860	425	520	605	**750**

The SSD is generally less than the PSD, indicating that not only is it safe for a pedestrian to cross with the proper PSD, but if a pedestrian stops in the crosswalk, a driver should easily be able to stop. There is no pedestrian dilemma zone in this scenario in most conditions. However, if the major road has a steep downgrade and the major-road speed is high, the required SSD will be greater than the available Near-Side PSD, as indicated by the bold values in Table 1. In these rare cases, a pedestrian dilemma zone exists.

Scenario 2 – Delayed View of Pedestrian at Beginning of Crossing Travel Lane

Now consider the scenario, where the driver for a variety of different possible reasons cannot see the pedestrian until the pedestrian has just entered the travel lane.

There are many examples of this type of scenario such as:

1. A sign or landscaping element that is near the crosswalk, which still allows the pedestrian to see the approaching vehicle but prevents the driver from seeing the pedestrian clearly on the side of the road.
2. Horizontal curvature in the road at/or near the intersection that limits the driver's natural viewing area from seeing a pedestrian on the side. Note that both the PSD and SSD calculation would change with a curved horizontal alignment, which is beyond the scope of this study but should be investigated.
3. A vertical crest near the intersection that limits viewing the crosswalk at an acceptable distance and thus the driver does not anticipate a pedestrian crossing.
4. A partially distracted driver.
5. A semi-static element such as a parked car or a stopped bus near the intersection.

6. A dynamic element such as vehicles passing the intersection and blocking the far-side travel lane from seeing the pedestrian even though the pedestrian has already seen the vehicle.

In this case, the vehicle will be travelling at speed for a period of time before seeing the pedestrian. For the near side, this represents an additional 4.9 s. This value accounts for the pedestrian perception-reaction time (2 s) plus an additional small time it takes for a pedestrian to walk the distance from the curb to the near-side lane in our initial assumption, which is common at many crossings (2.9 s). For the far side, this represents an additional 8.3 s. This value accounts for the pedestrian perception-reaction time (2 s) plus the time it takes for a pedestrian to walk the distance from the curb to the far-side lane (6.3 s), which is common at many crossings. So, in either case, the vehicle will travel a distance calculated as the speed multiplied by the amount of time before the pedestrian enters the travel lane, which depends on the approaching vehicle being of the near side or far side. A comparison of the required SSD (no vertical grades) and available PSD for this scenario is presented in Table 2.

TABLE 2 Comparison of SSD and PSD for Scenario 2: Delayed View of Pedestrian at Beginning of Crossing Travel Lane (Bold numbers indicate SSD > PSD)

Major-Road Speed (mph)	Near-Side Approaching Vehicle		Far-Side Approaching Vehicle	
	PSD (ft)	SSD (ft)	PSD (ft)	SSD (ft)
25	305	**335**	430	**460**
30	370	**420**	515	**570**
35	430	**505**	605	**680**
40	490	**595**	690	**795**
45	550	**685**	775	**910**
50	610	**785**	860	**1,035**

As noted, the required SSD is now greater than the required PSD for all major-road speeds. There is also a trend that as speed gets higher, the larger the difference in distance between PSD and SSD. This means that the potential for a crash with a pedestrian is higher at higher speeds should the pedestrian slow or stop in the crosswalk for any reason (e.g. falls, gets injured, gets distracted, or drops something).

With PSD not changing, SSD now changes and is different when comparing near-side and far-side approaching vehicles.

Scenario 3 – Delayed View of Pedestrian in the Middle of Crossing Travel Lane

The last scenario involves a driver not seeing a pedestrian until the pedestrian is in the middle of the travel lane. This means there is even more travel time for the vehicle before the driver notices the pedestrian in the crosswalk. Note, that the calculation of standard SSD is based on the assumption that the driver only perceives and reacts once there is an obstacle in the travel lane that must be avoided. Therefore, this scenario is unfortunately what can be best expected of a driver without blaming clear fault to the driver.

So now, it will take 6.7 s between the time the pedestrian initiates the crossing and the time the pedestrian is in the middle of the near lane. For the far lane, the pedestrian will reach the middle of the lane in 10.1 s. The results of required SSD and available PSD are shown in Table 3.

TABLE 3 Comparison of SSD and PSD for Scenario 3: Pedestrian Viewed by Driver In The Middle of Crossing Travel Lane (Bold numbers indicate SSD > PSD)

Speed (mph)	Near-Side Approaching Vehicle		Far-Side Approaching Vehicle	
	PSD (ft)	SSD (ft)	PSD (ft)	SSD (ft)
25	305	**405**	430	**530**
30	370	**495**	515	**645**
35	430	**595**	605	**770**
40	490	**700**	690	**900**
45	550	**805**	775	**1,030**
50	610	**920**	860	**1,170**

As expected, the difference between SSD and PSD is considerably worse than in Scenario 2.

DISCUSSION

To review again, the required PSD allows the pedestrian enough sight distance to be able to cross the street safely. In the ideal scenario, there is no significant risk to the pedestrian. If a pedestrian starts to cross and needs to stop for whatever reason, voluntarily or involuntarily, an alert driver who anticipates possibly stopping before the pedestrian begins the crossing should have enough time to stop before hitting the pedestrian.

Unfortunately, the ideal scenario is not very common, particularly outside high pedestrian volume locations. Nor can the ideal scenario be the expected behavior from a driver. This creates a pedestrian dilemma zone from both a safety and potentially legal perspective.

From a safety perspective, the pedestrian initially believes that the crossing is safe, but if something goes wrong, the pedestrian could be in great danger.

From a legal perspective, there is a definite period of time where no one can be blamed if there is a crash. If the pedestrian had enough PSD, then the pedestrian can claim that he or she made the proper decision to cross. If the driver does not see the driver until some point where there is not enough SSD but there was enough PSD, the driver cannot be faulted for failing to stop.

Could the engineer who designed the intersection be at fault? Currently, the answer is clearly no. There is not enough guidance currently for a designer, at least in North America, to consider this issue and be able to address it properly.

That is the main purpose of this paper: to recognize a serious safety problem in regards to pedestrian crossings that can be addressed in future research. Current pedestrian safety research is mainly focusing on substantive safety when the engineering community never addressed what would be considered nominal safety. A study on nominal safety would provide basic minimum requirements.

It is also not clear yet if engineers can solve this dilemma fully. Engineers cannot force drivers to look for pedestrians at every curb side of every intersection. Engineers cannot force pedestrians to cross only when a vehicle has enough SSD since theoretically a pedestrian should be able to cross with less of a distance. There are also certain dynamic aspects of PSD and SSD that engineers cannot control either. There may be some static and semi-static elements that could also be unavoidable.

CONCLUSIONS AND FURTHER RESEARCH

This paper showed evidence of a pedestrian dilemma zone at uncontrolled crossings where a pedestrian has the ability to cross a road safely but should anything go wrong in the crossing, a vehicle will not be able to stop in time. This happens in situations where a driver does not see or react to a pedestrian until the pedestrian starts crossing into the vehicle's travel lane or the pedestrian slows or stops in the crosswalk for any reason (e.g. falls, gets injured, gets distracted, or drops something).

Further research should expand the investigation of the pedestrian dilemma zone in regards to roadways with horizontal curves, vehicles that require a longer SSD such as trucks, pedestrians that require a longer PSD such as disabled or elderly pedestrians, and roadways that are on steeper grades at or near the intersection.

After there is enough research to clearly define the problem for most uncontrolled crossing scenarios, research should be conducted to start addressing how to eliminate or minimize pedestrian dilemma zones.

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