Discussion Paper No. 5.C

STOPPING SIGHT DISTANCE AS A MINIMUM CRITERION FOR APPROACH SPACING

prepared for

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DISCLAIMER

This discussion paper represents the viewpoints of the authors. Although prepared for the Oregon Department of Transportation (O.D.O.T.), it does not represent O.D.O.T. policies, standards, practices nor procedures.

GENERAL GOAL

This and other discussion papers were prepared to provide background, enhance understanding and stimulate discussion among individuals representing a variety of groups, agencies and interests who have concern in Oregon's highways.

SPECIFIC OBJECTIVES

The specific objectives of this discussion paper are to:

1. present the rationale for stopping sight distance as the criterion for the minimum approach spacing for safety.

2. present the analytical method to defend stopping sight distance as the minimum approach spacing.

3. present an example of conditions that require the stopping sight distance as the minimum spacing between approaches.

ACKNOWLEDGEMENTS AND CREDITS

Mr. Del Huntington is project manager for O.D.O.T. Mr. Mel Holmes, O.D.O.T, is responsible for technical review and direction. Dr. Robert Layton, Professor of Civil Engineering at O.S.U., is project director for T.R.I. Dr. Vergil G. Stover is consultant to T.R.I. on this project. This discussion paper was prepared by Dr. Robert D. Layton.

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INTRODUCTION

Background

The operational control and design of highway features are based on operational efficiency and safety. The ability of drivers to see and react to conflicts and hazards is a basic control on the safety of the roadway.

Various sight distance criteria may be used to design the roadway and appurtenances, depending on the allowable impact on traffic operations and the complexity of conditions. However, all of the roadway must meet the minimum stopping sight distance criterion. Visual blocks created by left turning vehicles makes it desirable to take account of stopping sight distance as the criterion for approach spacing.

Purpose

The purpose of this paper is to present the concept and research results on stopping sight distance as the minimum spacing between approach roads.

Perception Reaction Time

Perception reaction times are dictated by the human characteristics and factors. The perception reaction time includes the time to see (or perceive), understand (comprehend), make the action decision (decide) and react (respond) to any conflict or hazard. Some typical limitations on perception time are:

Time to shift eyes	≈	0.25^s
Time to focus	≈	0.25^s
Time to rotate his head	≈	0.5^s

Therefore,

Time to shift eyes and focus on new object	≅	0.5^s
Time to turn his head, shift eyes, and focus	≅	1.0^s

The minimum perception reaction time is about 0.5^{sec} according to controlled testing. As conflicts and information increase, the perception reaction time increases due to the greater complexity and confusion. Once the hazardous condition has been perceived, the driver must have adequate distance to stop safely.

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SIGHT DISTANCE MEASURES

The fundamental concept embodied in the AASHTO design criteria of minimum stopping sight distance is that:

> "A driver should have adequate distance to stop before hitting one clearly discernable hazard in the roadway."

Stopping Sight Distance

The stopping sight distance criteria uses a defined perception reaction time and a comfortable deceleration rate.

The stopping sight distance is based on:

Perception Reaction Time —

AASHTO	–	2.5 sec
Research (85th percentile)	–	2.0 sec
Alerted (control)	–	1.0 sec

Deceleration Rate —

AASHTO	~	10 ft/sec^2 (3 M/sec^2)
Current Research	~	6-9 ft/sec^2 (1.8-2.7 M/sec^2)

As indicated earlier, the minimum stopping sight distance must be provided for 100% of the highway system. The stopping sight distance according to AASHTO is based on a perception-reaction time of 2.5 seconds with a coefficient for a poor wet pavement of 0.28 at 70 mph to 0.40 at 20 mph. These coefficients of friction correspond to the deceleration rate of about 10 ft sec^2, as shown for a typical deceleration rate of 0.32:

$$f = \frac{a}{32.2}\,\text{ft/sec}^2$$

$$a = 0.32\,(32.2) = 10.0\,\text{ft/sec}^2$$

If the driver is driving in an alerted state, focussed on the road ahead, a perception-reaction time of 1 second may be used.

SIGHT DISTANCE MEASURES (Continued)

Decision Sight Distance

When multiple conflicts, distractions, and elements are present, decision sight distance might be used. This gives additional time for drivers to perceive and react to complex conditions.

The perception reaction time for decision sight distance ranges from about 6 to 10.5 seconds. The maneuvering time is to provide adequate time for a vehicle to brake to a stop or to make a path, speed or direction change, typically 4 to 4.5 seconds.

Intersection Sight Distance

The current intersection sight distance criteria in the AASHTO Greenbook is based on the approaching vehicle being slowed to 85% design speed (a 4 to 10 mph speed reduction) with a 2 second gap maintained. This maintains smooth operations with limited disruption to through traffic. It is not likely to result in shock waves or queuing unless the traffic is at or very near capacity.

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RATIONALE

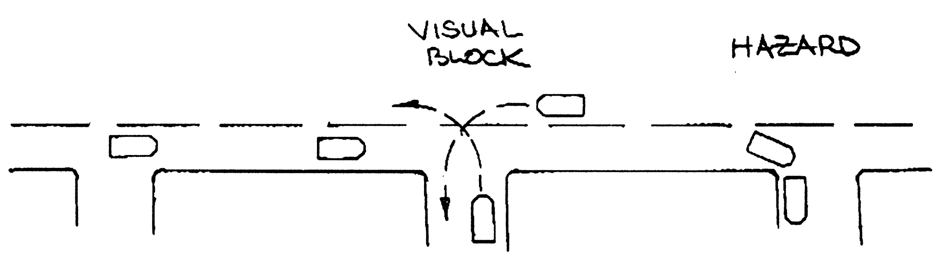
Rationale for Minimum Spacing of Driveways

The minimum spacing between driveways should be based on the condition where a driver must be able to stop safely if presented a clearly discernible hazard. For approaches, this means that a vehicle must be able to safely avoid any vehicle entering or exiting the roadway. For arterials, this limiting condition can occur when entering or exiting vehicles serve as visual blocks hiding a downstream hazardous condition.

Visual Blocks

Visual blocks occur every time a vehicle crosses the mainline, either a left turn in or a left turn out. An approaching mainline vehicle expects that they need only avoid the crossing vehicle to operate safely.

Drivers expect that any vehicle in their lane will get out of the way before they reach them, because they usually do. Drives tend to adjust their speeds and paths to miss turning or entering vehicles with an acceptable clearance, often not very large. This driver tendency generates a potentially hazardous condition with the visual screen or sight distance block, created by a vehicle turning into or out of an approach, particularly left turns in and out. The primary hazard is not between the mainline vehicle and the crossing turning vehicle, creating the visual block, but with a downstream obscured hazard.



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RATIONALE (Continued)

Potential Hazards

Potential hazards occur when vehicles are blocked from entering a driveway. This blockage may result from a spill back of queued vehicles exiting from the highway into a driveway with inadequate throat depth or inadequate driveway vertical alignment composed of abrupt slopes and short vertical curves. Also, the presence of pedestrians, bicyclists, or a wheelchair crossing the driveway throat could cause a stoppage in the right lane of traffic. The queuing of mainline traffic could also generate a stoppage that presents a hazard.

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ANALYSIS OF VISUAL BLOCK EFFECTS

The left turning vehicle blocks downstream stoppages from the view of the on-coming vehicles.

The important elements for this analysis include:

- stopping sight distance
- critical gap distance
- distance to clear the main roadway lane (or lanes).

Stopping Sight Distance

The stopping distance that is recommended for analyzing this condition uses an alerted perception reaction time of 1 second. Therefore, the alerted stopping sight distance is:

$$SSD = 1.47\,V_t + V^2/30\,f$$

Assuming 50 mph, for example:

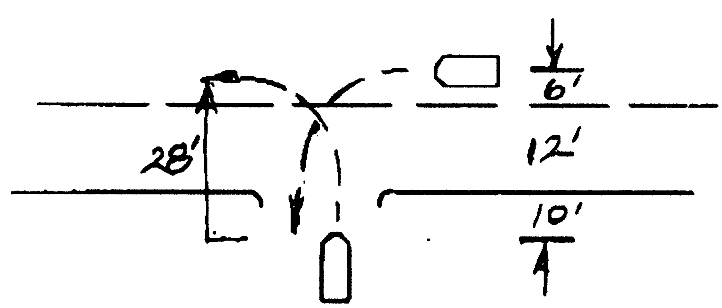
$$SSD = 1.47(50)(1) + 50^2/30(.3) = 350\text{ ft.}$$

Travel time to cover 350 ft:

$$t_{\substack{ALERT\\SSD}} = 350/50(1.47) = 4.8\,\text{seconds}$$

Time to Clear

The time to clear a lane of the approaching mainline traffic assumes that the vehicle exits or enters on a radius of about 28 ft. This assumes the vehicle to be centered in the lane, a lane width of 12 ft, and a setback from the extended curbs of 10 ft.



ANALYSIS OF VISUAL BLOCK EFFECTS (Continued)

Time to Clear (Continued)

Therefore, the travel distance is:

$$\text{T.D.} = \frac{1}{2}\pi R = \frac{1}{2}\pi(28) = 44\,\text{ft.}$$

The distance to clear the lane must include the length of the vehicle:

$$\text{Dist. to Clear} = 44 + 20 = 64\,\text{ft.}$$

The time to clear a lane while accelerating is:

$$S = \frac{1}{2}at^2$$

$$64 = \frac{1}{2}\left(5\,\text{ft}/\text{sec}^2\right)t^2$$

$$t = 5.0\,\text{second}$$

This time to clear is verified by Figure IX-33 from the AASHTO Greenbook, 1990, which yields a time of 5.1 seconds for 64 ft.

Typical Gaps in Traffic Streams

The critical gap for vehicles turning into an approach is 5.0 seconds, while a vehicle turning left from an approach is 6.5 seconds, according to the 1994 Highway Capacity Manual. The critical gap is as likely to be accepted as rejected, hence can be considered the 50% or median gap. The zero gap is smallest gap likely to be accepted, and are 4.0 and 4.8 seconds for left turns in and left turns out from an approach, respectively.

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EXAMPLE

The operations and sight distance for an example situation of 50 mph is now examined.

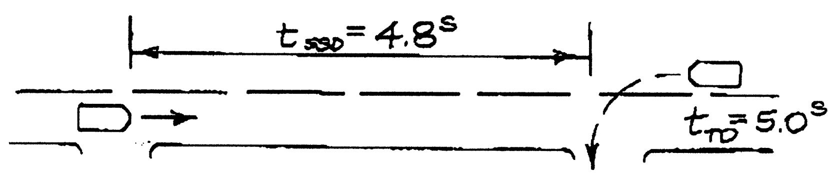
Summary of Controlling Times

A summary of the various controlling times plus the travel times corresponding to stopping sight distance at 50 mph is given below.

	Left Turn In	Left Turn Out
Time to Clear	5.0^s	5.0^s
Critical Gap	5.0^s	6.5^s
Zero Gap	4.0^s	4.8^s
Alerted SSD (350)	4.8^s	4.8^s
Comfortable SSD (475) (6 ft/sec^2)	6.5^s	6.5^s

No Visual Block

The following example assumes a speed of 50 mph for mainline vehicles. Mainline vehicles have time to stop if a left-in turning vehicle is visible and can complete the turn unimpeded.



If the left turning vehicle is forced to stop due to a blocked driveway, the approaching vehicle can stop comfortably only if the mainline vehicle is at least a stopping sight distance away. If the vehicle turns with a zero gap of 4.0 seconds, the stop cannot be made comfortably.

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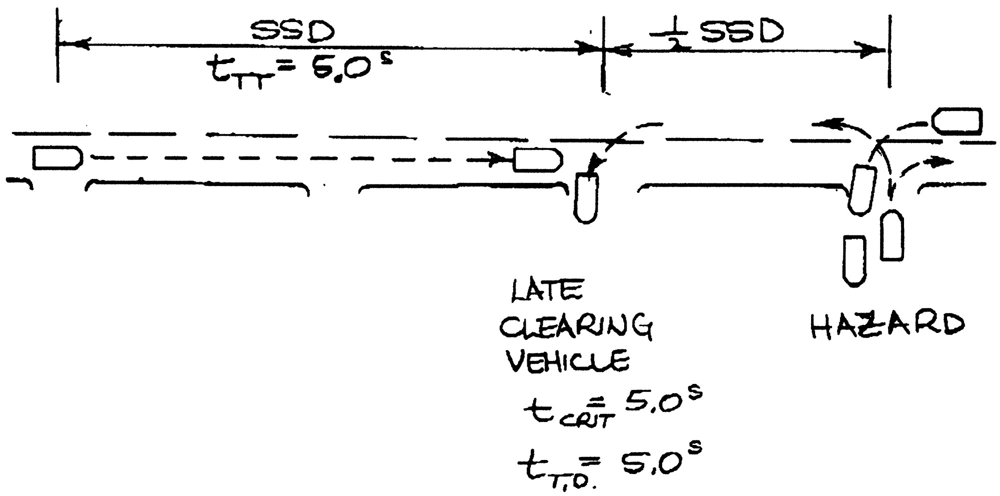
EXAMPLE (Continued)

Visual Block by Intermediate Driveway

If driveways are placed at a spacing of ½ SSD, a visual block can be generated by a turning vehicle. Assume: 50 MPH as driveways spaced at ½ SSD.



With a late clearing vehicle, the mainline vehicle driver "assumes" the vehicle will get out of his way and times his passage behind the vehicle with little or no slowing. At that point the mainline vehicle has ½ SSD to stop. A vehicle entering or leaving the driveway takes 6.5^s to clear the roadway. The vehicle while braking takes:

$$S = \frac{1}{2}at^2$$

$$\frac{1}{2}(350) - 1.47(50)(1) = \frac{1}{2}(10)t^2$$

$$t_{BRAKE} = 4.5^{sec}$$

Therefore, the time while the vehicle is stopping is:

$$\text{AVOIDANCE}\, t = 4.5 + 1 = 5.5^{sec}$$

EXAMPLE (Continued)

Visual Block by Intermediate Driveway (Continued)

For a perception reaction time of 2.5 sec, the time available to avoid the hazard is:

$$\frac{1}{2}(475) - 1.47(50)(2.5) = \frac{1}{2}(10)t^2$$

$$t_{BRAKE} = 2.3^{sec}$$

Therefore, the time while the vehicle is stopping is:

$$\text{AVOIDANCE}\, t = 2.3 + 2.5 = 4.8^{sec}$$

The vehicle pulling out of the driveway feels that the upstream turning vehicle is running interference. This is a marginal condition requiring the mainline vehicle driver to recognize immediately that a clearly discernable hazard exists, with the vehicle taking about 4.8 to 5.5 sec to reach the driveway. If the turning vehicle is stopped by queued vehicles, pedestrian, bicyclists, turning vehicles, or any other condition causing a vehicle to stop on the facility in the travel lane, then the vehicle only has ½ SSD to stop, clearly, a very hazardous condition. The only way to provide the full stopping sight distance for this condition is to use minimum driveway spacings equal to the stopping sight distance.

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RECOMMENDED SPACING CRITERIA

Minimum Approach Spacing

The minimum spacing between approaches should be stopping sight distance. In urban areas, the volume levels give a high probability that the combination of events resulting in a visual block and a vehicle stopped on the mainline occur quite often. Most likely, this combination of events happens more often than a 6” object falling onto the roadway. In rural areas, the volumes are typically very low and activity densities are also light. Consequently, it is not likely that driveways would need to be spaced closely. But, if the land use densities and volumes would require close spacing of approaches, the probability of a visual block and a stopped vehicle would also be high enough to require the stopping sight distance as a minimum spacing.

Spacing with Multiple Conflicts and Distractions

Where volumes are moderate, and conflicts are significant, the spacing between two approaches with a driveway between them, should not be less than decision sight distance, as shown below. The intermediate driveway represents a point of multiple conflict and distraction that would distract the driver.

Liability Implications

There are many locations on the existing street and highway system where the approach spacing is less than stopping sight distance. There is concern that this means that all locations that have an approach spacing of less than stopping sight distance are by definition unsafe and, therefore, are a safety liability. The courts have held that a change in standards does not make all locations design or located under a deficient standard unsafe by definition.

RECOMMENDED SPACING CRITERIA (Continued)

Liability Implications (Continued)

A greater than normal accident experience at these locations would be required to demonstrate that a location is unsafe.

Left Turn In Visual Block

From the time the left turning vehicle encroaches on the opposing lane of traffic, it takes 2.5 sec to totally cross and clear the opposing lane of traffic, accelerating to nearly 15 mph. During this time the oncoming driver is first distracted, then his/her vision is blocked. Consequently, if the driver arrives at 50 mph at the driveway, while the crossing vehicle has just entered, he/she needs the comfortable stopping sight distance to stop safely. Since the driver is distracted by the crossing vehicle, an unalerted perception-reaction time of 2.5 sec should be used. The last 0.3 second the approaching driver can see the hazardous condition at the far intersection, so the perception-reaction time could be reduced to 2.2 sec. This results in a minimum driveway spacing equal to the stopping sight distance with a 2.2 sec perception-reaction time, measured from the upstream edge of the driveway.

Left Turn Out Visual Block

The left turn out also distracts and blocks sight of the downstream approach intersection for 4.2 sec, for 15 mph speeds for the crossing vehicle. It also takes about 2.3 to 3.5 seconds for the vehicle to clear the lane completely, and 17.2 ft upstream from centerline of the driveway lane for left turns out. The difference of 0.5 to 1.1 sec could be taken as a reduction in perception-reaction time. This would be within 1 to 2 ft of the upstream edge of the driveway, if two lanes were provided. Therefore, the downstream driveway should be no closer than the stopping sight distance from there. Measuring the stopping sight distance from the centerline of the driveway gives some added distance for the length of the vehicle stopped at the driveway entrance. As before, a reduced perception-reaction time of about 2 seconds would be appropriate.

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RECOMMENDED SPACING CRITERIA (Continued)

Right Turning Vehicle Visual Block

A right turning vehicle can also serve as a visual block to a possible hazard at a downstream street approach. It would take about 2.4 seconds for a vehicle to turn a into a driveway far enough for the rear of the vehicle to clear the right lane. A 50 mph vehicle coming up from behind the right turning vehicle would cover 176 ft in that time period.

As the vehicle turns to the right and the 50 mph vehicle closes on it, the visual picture continually changes as the turning vehicle turns out of the way. The 50 mph vehicle has adequate visibility at about 175 ft upstream of the driveway where the right turning movement is made. The alerted stopping sight distance for 50 mph is 350 ft. Therefore, the driveway could be spaced at half of stopping sight distance for this situation. An alerted perception-reaction time of 1 second is assumed because the driver is following a turning vehicle so the driver should be more aware of traffic conditions.

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REMEDIAL MEASURES

One remedial measure is to locate driveways and approaches no closer than alerted stopping sight distance, at a minimum. Any drive or approach with narrow throat width or steep or abrupt vertical alignment should not be located closer than stopping sight distance. On high volume, higher class facilities, the perception-reaction time may be increased to the normal 2.5 seconds used in the AASHTO Greenlight Book.

Where existing driveway spacings are closer than stopping sight distance, a number of countermeasures may be used to allow closer spacings. These countermeasures include:

- placement of a nontraversable median
- use of a right turn lane, or right turn bay
- flat vertical alignment design
- adequate throat width and throat depth
- set back of sidewalks where high pedestrian volumes exit.

Another less attractive option is to reduce the speeds of operation on the major roadway to a level compatible with the driveway spacing, and other access management elements, present.

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CONCLUSIONS AND RECOMMENDATIONS

Stopping sight distance is a logical criterion for approach spacing where the spacings of driveways should be determined based on the nature and frequency of conflicts present. The nature of conflicts refers to the type of movements present, that is, through movements, left turns, right turns. The frequency of conflicts refers to the nearness of approaches and the volume levels.

Spacing criteria recommendations are:

1. With left turns present for driveways:

   Spacing = AASHTO Stopping Sight Distance

2. Only right turns with nontraversable median:

   Spacing = ½ Alerted Stopping Sight Distance

3. The stopping sight distance may be calculated based on various perception reaction times, depending on volumes, speeds, and highway class.

4. Driveway spacing with left turns present may be less if a right turn lane is provided. No research or data are presently available to indicate how much less the spacing may be.

5. A risk assessment of the likelihood of a visual block and stoppage may be employed to determine appropriate spacing.