The Kiewit Center for Infrastructure and Transportation

Decision Sight Distance

Discussion Paper #2

by

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DISCLAIMER

This background paper represents the viewpoints of the authors. Although initially prepared for the Oregon Department of Transportation (ODOT), it does not represent ODOT policies, standards, practices nor procedures.

GENERAL GOAL

This and other background 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 for the development of access management policies, standards and practices.

SPECIFIC OBJECTIVES

The specific objectives of this discussion paper are to:

1. Summarize the literature and traditional knowledge regarding decision sight distance.

2. Summarize research and the current state of the art on the factors and elements of driver behavior and traffic operations that affect decision sight distance.

3. Review current criteria on decision sight distance within the context of access management.

4. Identify questions and issues regarding the appropriate criteria and use of decision sight distance in access management applications.

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OVERVIEW

Background

The safe operation of all highway facilities, including intersections, requires the consideration of three primary elements for safe roadway operations: the driver, the vehicle, and the roadway. An understanding and consideration of each of these elements is necessary to define appropriate sight distance criteria. Human factors associated with the driver's performance must take account of both physical abilities and psychological influences. The size, weight, and braking ability of vehicles are of particular importance for the safe operation and stopping of vehicles. The roadway geometric design features, obstacles to sight at the roadsides, pavement surface condition, and climatic conditions impact the safety on the roadway and sight distance requirements. Each of these elements and their interactions govern the development and specifications of sight distance criteria and standards.

The determination of sight distance requires the definition and consideration of seven design variables:

Primary Stopping Sight Distance Factors

- Perception-reaction time
- Driver eye height
- Object height
- Vehicle operating speed
- Pavement coefficient of friction
- Deceleration rates
- Roadway grade

An important study on stopping sight distance was published as NCHRP Report 400, "Determination of Stopping Sight Distance" (1). This reference presents recommended revisions to the AASHTO "Policy on Geometric Design" for the 2001 and 2004 Editions (2,3).

Most of the recommended changes based on the NCHRP Report were included in the 2001 AASHTO "Policy on Geometric Design" (i.e., 2001 Greenbook). However, a number of state DOTs have opted to retain the criteria from the 1990 and 1994 AASHTO Policies (1990 and 1994 Greenbooks), rather than accept the significant changes in height of objects, from 0.5 ft. (150 mm) to 2.0 ft. (600 mm), for stopping sight distance (4,5).

Content

This background paper summarizes the literature, standards and traditional knowledge on stopping sight distance. The primary emphasis of this discussion is on the driver behavior and traffic operation conditions that influence the distance required for drivers to stop or maneuver their vehicles safely.

The discussion includes information drawn from policies, standards and current research. The primary sources of the policies and standards are the AASHTO Policy on Geometric Design, 1990 Edition (English Units), 1994 Edition (Metric units) and 2001 Edition (both units), and the Oregon Highway Design Manual. The standards and criteria for stopping sight distance have evolved since the 1920s. The changes in vehicle sizes and operating characteristics, driver experience and behavior, and highway technology cause a continued evolution of sight distance policies and standards.

Issues

Sight distance criteria have impact on virtually all elements of highway design and many elements of the operation/control. The roadway geometric design features, presence of obstacles to sight at the roadsides and the pavement surface condition are fixed by sight distance requirements. The nature of traffic controls and their placement must take account of sight distance requirements. At times, the effects of traffic stream conditions, such as traffic queues, must be viewed from adequate distance to stop. Driveway locations, access conflicts and roadside activities influence the roadway operations and safety.

Adequate stopping sight distance must be provided on 100% of the street and highway system so a driver with the standard eye height can see an object of standard height with sufficient time to stop safely. This assumes a certain level of alertness on the part of the driver and no influence on a driver’s perception and reaction due to added complexity of traffic, control and local environmental conditions. Some research has indicated that driver behavior, expectations and alertness change with the type of area and with the operating conditions on the roadway. The aging of our driver and pedestrian populations is of particular concern with the concomitant impacts on their cognitive abilities and behavior.

The determination of stopping sight distance requires the definition of six of the seven primary design variables. It is not necessary to specify both deceleration rate and a design coefficient of friction because they both measure the required rate of slowing for the vehicle

Under some conditions the added complexity of traffic, local activities and driver expectancy may require longer times to accommodate long perception-reaction times due to situation complexity, expectations and alertness, as well as longer distance for normal vehicle maneuvers of lane changing, speed changes and path changes, or for stopping.

These increased perception-reaction times and longer maneuvering distances required by greater complexity are accommodated by decision sight distance. Decision sight distance is applied where numerous conflicts, pedestrians, various vehicle types, design features, complex control, intense land use, and topographic conditions must be addressed by the driver.

- Stopping sight distance is applied where only one obstacle must be seen in the roadway and dealt with.

- Decision sight distance is different for urban versus rural conditions, and also for maneuvers ranging from stopping to speed, path or direction change within the traffic stream.

Consequently, there are five different cases for decision sight distance that are currently defined in the AASHTO Policy on Geometric Design.

Decision Sight Distance Cases

- Rural Stopping
- Urban Stopping
- Rural Speed/Path/Direction Change
- Suburban Speed/Path/Direction Change
- Urban Speed/Path/Direction Change

Stopping in the context of decision sight distance, as distinct from stopping sight distance, may be necessary to avoid a vehicle that is forced to stop for some traffic condition, such as a queue of vehicles, rather than an object in the roadway.

In view of the complexity and variations in drivers’ expectancy for situations associated with access management, decision sight distance is a more logical requirement for many access management situations than stopping sight distance. More cases of decision sight distance, or sight distance for access management, are likely required at access points and where access management strategies are employed, such as direction at median openings.

Sight Distance as an Access Management Measure

Stopping sight distance is required at all locations along the highway, to see an object in the roadway with enough distance to stop. The stopping sight distance is typically required at all intersections and approaches.

The decision sight distance is the control for many access management situations where:

1. driver workload is heavy, driver expectations vary or drivers are likely to be misled, such as in the vicinity of interchange ramp terminals or where continuous two-way left turn lanes are present.

2. complex operations or design features exist, such as unsignalized intersections, approaches on multilane highways or directional median openings.

The decision sight distance may be applied:

1. to control vehicles that must perceive and react with time to stop behind queuing vehicles.

2. to assure adequate time for a speed, path or direction change, as would occur where vehicles must weave over to a left turn lane or to an approach on the right.

3. to accommodate pedestrians at crossings.

4. to deal with bicycles and bicycle lanes at intersections or major driveways.

5. to accommodated transit stops in and adjacent to through lanes.

6. to mitigate the added difficulties created by through trucks entering, leaving or double-parking in through traffic lanes.

Questions to be Answered

The selection and application of a sight distance criteria for access management require that a number of questions be answered. The most important questions are identified as follows:

1. Should a safe coefficient of friction or acceptable deceleration rate be used to define the deceleration of vehicles? What deceleration rates are implied by the coefficient of friction used for design? What deceleration rates are typical and comfortable for drivers? What deceleration rates should be used for trucks and buses?

2. What height of eye should be used for sight distance? What proportion of the drivers should the height of eye criterion represent? What height of eye values should be used for trucks, particularly in an urban environment?

3. Is a 2 ft. (600 mm) object reasonable for decision sight distance? Should the heights of the object be different for decision sight distance? Should the height of the object be situation-specific?

4. Should trucks be treated specifically or should the higher eye height be assumed to offset the longer stopping distance required by trucks?

5. Should the decision sight distance be based on design speed, vary according to conditions, or be set at the 85th percentile speed?

6. What unique operating conditions warrant unique perception-reaction times?

PERCEPTION-REACTION TIMES

PIEV Process

The perception-reaction time for a driver is often broken down into the four components that are assumed to make up the perception reaction time. These are referred to as the PIEV time or process.

PIEV Process

• Perception	the time to see or discern an object or event
• Intellection	the time to understand the implications of the object's or event's presence
• Emotion	the time to decide how to react
• Volition	the time to initiate the response action, for example, the time to engage the brakes

Current Design Perception-Reaction Time

Human factors research defined the required perception-reaction times as follow for (2,3,4,5):

- design 2.5 sec
- operations/control 1.0 sec

These perception reaction times were based on observed behavior for the 85th percentile driver; that is, 85% of drivers could react in that time or less. More recent research has shown these times to be conservative for design.

Wortman and Mathias (6) reported both the "surprise" and alerted 85th percentile perception reaction times for control. The time perception-reaction was measured after the yellow indication until brake lights appeared, and was in an urban environment

The Wortman et al., research found:

- alerted 85% perception-reaction time 0.9 sec
- "surprise" 85% perception-reaction time 1.3 sec

Perception-Reaction Time Research

Recent studies have checked the validity of 2.5 seconds as the design perception reaction time. Four recent studies have shown maximums of 1.9 seconds as the perception-reaction time for an 85th percentile time and about 2.5 seconds as the 95th percentile time.

Brake Reaction Times Studies	85th	95th
Gazis et al. (7)	1.48	1.75
Wortman et al. (6)	1.80	2.35
Chang et al. (8)	1.90	2.50
Sivak et al. (9)	1.78	2.40

Perception-Reaction Times by Road Type

Some researchers have suggested that the perception-reaction should reflect the complexity of traffic conditions, expectancy of drivers and the driver's state. They suggest that the perception reaction times may be altered accordingly, as shown in Table 1 (6).

Table 1. Perception-Reaction Times Considering Complexity and Driver State

	Driver's State	Complexity	Perception-Reaction Time
Low Volume Road	Alert	Low	1.5 s
Two-Lane Primary Rural Road	Fatigued	Moderate	3.0 s
Urban Arterial	Alert	High	2.5 s
Rural Freeway	Fatigued	Low	2.5 s
Urban Freeway	Fatigued	High	3.0 s

Perception-Reaction Times for the Elderly Driver

The perception-reaction times for elderly drivers have not been found to be significantly longer than the average younger driver. However, the changes in physical and cognitive abilities for the elderly could have significant impacts on their abilities to understand conditions and react safely. Consequently, AASHTO has recommended that a design perception-reaction time of 3.0 seconds be used (10).

HUMAN FACTORS

An appreciation and understanding of human factors, driver behavior and abilities are needed to determine the sight distance criteria. The physical abilities and psychological limitations of drivers impact these criteria, and are reviewed here to obtain perspective.

Visual Ability

The primary stimulus for operation and safe control of vehicles is eye sight. The physical composition of the eye and its functioning constitute limits that must be considered when developing sight distance criteria. For the average younger driver, the average visual acuity is 20/20. The visual clutter along arterials is problematic for the visual acuity of drivers, especially the elderly.

Visual Acuity

3-4° cone	best vision – can see texture, shape, size, color, etc.
10° cone	clear vision – critical traffic control devices must be in this cone
20° cone	satisfactory vision – regulatory and warning traffic control devices should be this cone of vision
~ 90° cone	peripheral vision – only movement can be seen with this vision

Drivers focus their attention down the roadway in the cone of clear vision at 3 to 4 times the stopping distance. They then shift their vision to the right and left to keep track of traffic conditions, pedestrians and local activities. The eye movement time includes the time required for a driver to shift their eyes and to focus on an object.

Eye Movement Time

Shift to New Position	0.15-0.33 sec
Fix or Focus on Object	0.1-0.3 sec

It takes roughly 0.5 second for a driver to shift his eyes and focus. Thus, a full cycle to right and back to the left takes about 1 second. If there is glare, it takes 3 seconds to recover full visual acuity and 6 seconds to recover from bright to dim conditions

Visual Ability of the Older Driver

For drivers over 65, the average static visual acuity has dropped to 20/70 (11). The ability to see detail in signs, markings and geometric features is governed by the static visual acuity of the driver. The static visual acuity is dependent on the background, brightness, contrast and time for viewing.

Dynamic visual acuity is the ability to resolve the details of a moving object. Dynamic visual acuity is diminished as speed of the object increases, however it improves as time of viewing illumination and familiarity increase (12). Dynamic visual acuity related to crash involvement regardless of age. However, there is gradual deterioration of dynamic visual acuity with advancing age.

Contrast sensitivity is the ability of drivers to analyze contrast information and see patterns in the visual field. A study by M.S. Horswill, et al., (13) found that hazard perception-response time increases significantly with loss in contrast sensitivity. Contrast sensitivity is more important than visual acuity for night time driving safety and operations. Older drivers have less contrast sensitivity than younger drivers.

Research has found reduced contrast sensitivity and static visual acuity for elderly drivers when there is glare (10). The ability to assess distance or depth perception by shifting from near view to far view is lost to elderly drivers by the hardening of the optic lens and the weakening of the ocular muscle. This results in the inability of the elderly to judge speeds of oncoming vehicles, assess gaps between vehicles and determine the distance to roadside features. These losses in ability are critical for making left turns and crossing through traffic safely.

Virtually all vision measures deteriorate with lower levels of illumination. Less illumination is especially problematic for the elderly driver. Drivers by age 75 need about 32 times as much illumination to see well as they did at age 25 (10).

Human Mind Performs Sequential Processing

Humans are sequential processors; that is, drivers sample, select and process information one element at a time, though very quickly. Therefore, complex situations create unsafe or inefficient operations because it takes so long for drivers to sample, select and process the information. This means that as complexity increases a longer perception-reaction time should be available. The visual acuity limitations, visibility constraints of glare/dimness recovery and complexity of traffic conditions, when taken together, require much longer perception-reaction times or decision times.

Working Memory Capability

Working memory capacity relates to the mutual cognitive ability to process new information while storing and analyzing known information. The working memory capacity is the amount of information that a driver can receive and process at a time. It is felt that the working memory capacity of the elderly is less than that for younger drivers. A rule of thumb estimates the average workload of seven items to roughly define the typical working memory capacity.

High volume, high speed arterials with multiple access points, numerous conflicts, median openings, pedestrians and traffic control can provide a workload that taxes the working memory capacity. As speeds and volumes increase, drivers pay less attention to activities in the periphery at the roadside, thus access management features require longer perception-reaction times.

Attention to the driving task is extremely important for safe driving. It has been estimated that 25-50% of crashes result from inattention (14). Selective attention requires selection of the most critical information out of the volume of information presented. Selection and appropriate use of critical information is basic to safe driving. Elderly drivers have more difficulty selecting the critical information, and it takes them longer to process it. Care must be taken to provide adequate viewing and response time, where conflicts are numerous, conditions are complex, and speeds and volumes are high to limit driver workload to acceptable levels.

Driver Expectancy

Drivers are led to expect a particular operation condition based on the information presented to them. They use both formal and informal information.

- Formal information – this includes the traffic-control devices and primary geometric design features of the roadway, but does not include the roadside features, such as ditch lines, guardrail, and other street furniture.

- Informal information – this includes roadside features and also land use features, such as brush lines, tree lines, fences and information signing. It includes all information that is not formal.

Drivers develop expectations on how to drive a roadway through experience, training and habit. At times these expectations are in error because they use inappropriate informal information, or the formal information provided is not proper or gives mixed messages. Often, the information at a location is conflicting, and drivers who are familiar with the location read traffic conditions differently than unfamiliar drivers. For example, driver error due to driver expectancy can occur where the location of pavement joints (informal information) conflict with lane markings (formal information). A driver may see and follow the pavement joints rather than the pavement striping, particularly on dark, wet nights.

Increased perception reaction time is needed to allow time for drivers to make the proper decision when information conflicts and driver expectancy may be in error.

Traffic conditions vary dramatically on major facilities; consequently, the information that drivers receive from other vehicles and traffic conditions is constantly changing. Therefore, high volume and high speed conditions with the added complexity and heavier driver workloads require longer decision times and compound any problems arising from driver expectancy.

DRIVER EYE HEIGHT

2001 and 2011 current AASHTO Design Driver Eye Heights:

Passenger Cars	3.5 ft (1080 mm)
Trucks	7.6 ft (2330 mm)

In general, the required height of eye for drivers for decision sight distance should be the same as for stopping sight distance.

The height of eye for design has decreased with time as the vehicle sizes and dimensions changed. The design height of eye up to the year 2000 was 3.5 ft. (1070 mm) (4,5). This has reduced from 5.5 ft. (1680 mm) in the 1920s to 3.75 ft. (1150 mm) in 1965. A moderate change in driver's eye height results in a small change in stopping sight distance and in the required length of vertical curves (6). Driver eye height for trucks is not normally of concern because they are significantly higher than passenger cars. The higher height of eye for trucks is assumed to compensate for their longer stopping sight distance. However, truck eye height may be an issue where the stopping sight distance is controlled by horizontal alignment, such as cut slopes, or other vertical sight obstructions, such as a hedge, overhanging limbs or signs. Typical values for height of eye for trucks are from 71.5 in. (1820 mm) to 112.5 in. (2860 mm) with an average eye height of 93 in. (2360 mm). In the past, height of eye of 8.0 ft. (2400 mm) has been used for design for trucks.

The NCHRP Report 400 presented the results of some measurements made on height of eye for various vehicles. These results are shown in Table 2.

Table 2. Current Height of Eye Statistics

	Passenger Cars		Multipurpose Vehicles*		Heavy Trucks	
	(ft)	mm	(ft)	mm	(ft)	mm
Mean	(3.77)	1149	(4.86)	1482	(8.03)	2447
Standard Deviation	(0.18)	55	(0.43)	130	(0.35)	107
5th Percentile	(3.48)	1060	(4.15)	1264	(7.56)	2304
10th Percentile	(3.55)	1082	(4.28)	1306	(7.64)	2329
15th Percentile	(3.59)	1094	(4.37)	1331	(7.68)	2341

*These include pickups, utility vehicles, vans, etc.
Source: NCHRP Report 400, Transportation Research Board, Washington, DC, 1997 (1).

There was some indication that the height of eye adopted by AASHTO would be reduced to 1 meter, or 3.28 ft., since the passenger car fleet had continued to decrease in height. However, the increased use of pick-ups, SUVs and vans has caused the overall driver’s eye height to increase. The NCHRP Report 400 has recommended a height of eye of 3.54 ft. (1080 mm).

This change of height of eye of 3.54 ft. (1080 mm) has been adopted in the 2001 AASHTO Greenbook; also it adopted an eye height for trucks of 7.6 ft. (2330 mm), with a stated range of 6-8 ft. (1800 mm to 2600 mm). The 2011 AASTO Greenbook retained the eye heights for both cars and trucks.

OBJECT HEIGHT

The object heights for decision sight distance are currently the same as for stopping sight distance, according to AASHTO:

Object Height (AASHTO 2001 & 2011)	2 ft. (600 mm)
Object Height (CALTRANS, ODOT, WsDOT	0.5 ft. (150 mm)

The object height that has been used for stopping sight distance has been 6 in. (150 mm) since 1965. The standards have required that a driver should be able to see and stop before hitting an object of 6 in. (150 mm) in height everywhere on the roadway. This arbitrary value recognized the hazard an object of that height or larger would represent, since 30% of the compact and sub-compact vehicles could not clear a 6 in. (150 mm) object (5). It also suggested that the 6 in. (150 mm) object height was a rational trade-off between the need to see the pavement and the cost to provide that sight distance. Under some circumstances the height of the tail-light at 1.5 ft. (450 mm) to 2.0 ft. (600 mm) were recognized as a more appropriate object to be viewed, in particular at under-crossings, where a truck would be the design vehicle with its height of eye. A study undertaken by CALTRANS for sight distance on HOV lanes found an 85% tail-light height of 2.5 ft. (760 mm).

The current AASHTO standard for object height in the 2001 AASHTO Greenbook was increased to 2.0 ft. (600 mm) based on a car's tail light (2). CALTRANS, ODOT and WSDOT retained the 0.5 ft. (150 mm) object height for both stopping sight distance and decision sight distance, recognizing all of the aspects of safe highway design and visibility that are provided by this lower height of object of 0.5 ft. (150 mm). Discussion of the safety implications of the use of a 2.0 ft. (600 mm) height of object is given in Appendix A of the paper, "Stopping Sight Distance: A Discussion Paper #1," Technical Report 11-1, The Kiewit Center, Oregon State University, Corvallis, OR, 2011.

The object height at intersections has been 4.25 ft. (1300 mm), which is the same required for passing sight distance (4,5). This criterion assumes that being able to see the top or roof of a passenger car is adequate as the object for intersection sight distance (15). This ignores the difficulty in distinguishing the thin splinter of the car roof from other objects, particularly if the car is of an earth tone color. It also ignores the difficulty in seeing the car at night with the headlights at about 2 ft. (600 mm) height, even assuming some upward diffusion of the lights. A height of object of 3.5 ft. (1080 mm), the 2001 AASHTO standard for passing sight distance, would yield a target of 9-10 in. (220-250 mm) in height, which would assure an approaching vehicle would be seen. Where the decision sight distance criteria is applied to the back of queue or to avoid vehicles elsewhere in the traffic stream, the object height may be either the height of the vehicle or the height of the tail-light. The height of tail-light according to NCHRP Report 400 must be no lower than 15 in. (380 mm) nor higher than 72 in. (1830 mm); the mean tail-light height was found to be 2.38 ft. (726 mm) for passenger cars. This would typically result in an object height of 1.5-2.5 ft. (460-760 mm). For vehicles entering the roadway at night, the height of the headlights may be used, or 2 ft. (600 mm). The AASHTO standard for object height is 3.5 ft. (1080 mm) for both passing sight distance and intersection sight distance, according to the 2001 and 2011 Greenbook.

Pavement sight distance should be provided for decision sight distance in channelized intersections, on turning roadways, or at locations where the alignment may take an unexpected change in direction. This is provided with an object height of 0.0 ft. (0.0 mm). This provides for the driver to be able to see markings and curb cuts.

In summary:

	2001 & 2011 AASHTO	2009 CALTRANS	2001 ODOT	2011 WSDOT
Object for stopping sight distance	2.0 ft. (600 mm)	0.5 ft. (150 mm)	0.5 ft. (150 mm)	0.5 ft. (150 mm)
Object for decision sight distance	2.0 ft. (600 mm)	0.5 ft. (150 mm)	0.5 ft. (150 mm)	0.5 ft. (150 mm)
Object for passing sight distance	3.5 ft. (1080 mm)	4.25 ft. (1300 mm)	3.5 ft. (1080 mm)	3.5 ft. (1080 mm)
Object for intersection sight distance	3.5 ft. (1080 mm)	4.25 ft. (1300 mm)		3.5 ft. (1080 mm)

Recommended Object Heights for Decision Sight Distance

Rear of queue	2.0 ft. (600 mm)
Pavement markings	0.0 ft. (0.0 mm)
Curb cuts	0.5 ft. (150 mm)
Median openings	0.5 ft. (150 mm)
Pedestrians*	2.0 ft. (600 mm)
Bicycles**	2.0 ft. (600 mm)
Animals	1.0 ft. (300 mm)
General safety***	0.5 ft. (150 mm)

* Considers wheelchair
** Considers recumbent bicycles
*** Composite of all objects

VEHICLE SPEED

The speed employed in the analysis of stopping sight distance and decision sight distance is typically the design speed in Oregon and other states, in particular for vertical sight restrictions. Until the 2001 AASHTO Policy, AASHTO allowed the running speed to be used, since the design coefficient of friction was for wet pavements, and drivers were expected to slow on wet pavements. However, AASHTO indicates that recent data show that drivers do not slow appreciably on wet pavement. The 2001 AASHTO Policy on Geometric Design has eliminated stopping sight distance based on running speed, and design speed is specified (2). Therefore, design speed should be used to determine sight distance criteria. When the facility is an existing facility, or design speed is not known, the operating speed on the roadway can be used.

The relationship between average speed, 85th percentile speed and design speed is not well understood. However, the approximate relationship can be defined as follows, based on the standard normal distribution. The design speed has been defined as about the 95th to 98th percentile speed; therefore:

Average operating speed	=	mean speed
85th percentile speed	=	mean speed + 1 std. deviation
Design speed (97% speed)	=	mean speed + 2 std. deviations

Typically, the standard deviation for speeds is about 5-6 mph. Thus, if the standard deviation is not known, a rule-of-thumb is:

85th percentile speed is mean operating speed + 5 mph (10 km/h)

Design speed is 85th percentile speed + 5 mph (10 km/h)

Small variations in speed result in very large differences in stopping sight distance, since stopping sight distance varies as the square of velocity. Decision sight distance varies linearly with the speed, so the speed definition is not as critical.

PAVEMENT COEFFICIENT OF FRICTION

Until 2001, the coefficients of friction used for design on arterials or open highways in the 1990 and 1994 AASHTO Green Books (4,5) were based on the results of a number of studies that measured the locked-wheel skid resistance on poor wet pavements. These AASHTO design values corresponded to a comfortable deceleration rate of 6 to 8 mph/second (9.6 to 12.9 kph/sec); they are shown in Table 3.

The 2001 AASHTO Policy on Geometric Design uses a deceleration criterion to determine the braking distance term for stopping sight distance of 11.2 ft/ sec^2 (3.4 m/sec^2). This is retained as the standard in the new 2011 Greenbook.

Table 3. 1990 and 1994 Design Coefficients of Friction for Stopping Sight Distance

Design Speed		Running Speed		1990 and 1994 AASHTO Coeff. of Friction for f_{WET}	AASHTO Coeff. of Friction for trucks, f_{TR}	Acceptable Deceleration for Trucks, a_{TR} ft/sec^2
(20 mph)	30 kph	(20 mph)	32 kph	0.40	0.25	8.1
(30 mph)	50 kph	(28 mph)	45 kph	0.35	0.21	6.8
(40 mph)	65 kph	(36 mph)	58 kph	0.32	0.19	6.1
(50 mph)	80 kph	(44 mph)	71 kph	0.30	0.18	5.8
(60 mph)	100 kph	(52 mph)	84 kph	0.29	0.17	5.5
(70 mph)	115 kph	(58 mph)	93 kph	0.28	0.16	5.1

With trucks the safe coefficient of friction for braking is less than for passenger cars because a truck can't safely make a locked-wheel stop without the risk of losing control. Therefore, the deceleration rate when stopping is less for trucks than for passenger cars, on the order of 3.5 mph/sec (5.6 kph/sec) to 5.5 mph/sec (8.9 kph/sec); these decelerations correspond to "f" values of 0.16 to 0.25, respectively. Design coefficients of friction based on truck performance are given in the last column of Table 3 above. Note that the coefficient of friction corresponding to a deceleration rate is determined from the relationship:

$$f = \frac{a\,(\text{mph/sec}) \times 1.4667\,(\text{fps/mph})}{32.2\,\text{f}ps^2}$$

(U.S. Customary)

$$f = \frac{a\,(\text{m}/\text{sec}^2)}{9.8\,(\text{m}/\text{sec}^2)}$$

(Metric)

The coefficient of friction corresponding to the design deceleration rate of 11.2 ft/sec^2 is:

$$f = \frac{a\,(\text{ft/sec}^2)}{32.2\ (\text{ft/sec}^2)} = \frac{11.2\,(\text{ft/sec}^2)}{32.2\,(\text{ft/sec}^2)} = 0.35$$

This matches the design coefficient of friction for 30 mph, for 1990 and 1994 AASHTO. Thus, the required stopping distances are shorter for speeds greater than 30 mph, according to the 2001 and 2011 AASHTO Greenbooks.

SIGHT DISTANCE CALCULATIONS

The decision sight distance and stopping sight distance are comprised of the distance to perceive and react to a condition plus the distance to stop:

$$SSD = 1.47\,Vt + \frac{V^2}{30\,(f \pm g)} \qquad \text{(U.S. Cust.)}$$

or

$$SSD = 1.47\,Vt + \frac{V^2}{30\,(\frac{a}{32.2} \pm g)} \qquad \text{(U.S. Cust.)}$$

$$SSD = 0.278\,Vt + \frac{V^2}{254\,(f \pm g)} \qquad \text{(Metric)}$$

or

$$SSD = 0.278\,Vt + \frac{V^2}{254\,(\frac{a}{9.81} \pm g)} \qquad \text{(Metric)}$$

where SSD = required stopping sight distance, ft. or m,
V = speed, mph or kph
t = perception-reaction time, sec., typically 2.5 sec. for design
f = coefficient of friction, typically for a poor, wet pavement
g = grade, decimal

The 1990 and 1994 AASHTO Greenbooks provided for a minimum and a desirable stopping sight distance. The desirable stopping sight distance was provided based on the design speed and a coefficient of friction for a poor, wet pavement. The minimum stopping sight distance was provided based on the running speed and a coefficient of friction of a poor, wet pavement. The NCHRP Report 400 recommended new design criteria to AASHTO using a deceleration rate of 11.2 ft/sec^2 or 3.4 m/sec^2 (0.34 g) instead of the wet coefficient of friction. The running speed is the average operating speed on the roadway and is typically less than design speed, about 83% to 100% of design speed for 20 mph to 70 mph (113 kph to 32 kph), respectively. As indicated previously, AASHTO has found that drivers do not slow on wet pavement so the use of running speed is not appropriate to determine stopping sight distances.

For the “speed path and direction change” distance, for decision sight distance is found by;

$$DSD = 1.47Vt \qquad \text{(U.S. Cust.)}$$

$$DSD = 0.278Vt \qquad \text{(Metric)}$$

where t = the perception-reaction time plus the maneuver time

V = speed, mph or kph

It is interesting to note that with low beam headlights, a driver may be able to see from 120 ft. to 350 ft. (37 m to 107 m) and with high beams from 200 ft. to 500 ft. (61 m to 152 m). Thus, drivers driving faster than 55 mph (88 kph) at night are overdriving their headlights for a stopping sight distance of 495 ft.

The running speed variable that was employed for the stopping sight distance determination yielded a condition that approximated the operating speed condition. For decision sight distance the 85% speed may be a useful way to approximate that operating speed condition, particularly for urban conditions.

CURRENT DECISION SIGHT DISTANCE CRITERIA

Decision Sight Distance Appropriate for Access Management

There are many situations where stopping sight distance is not sufficient for safe and smooth operations, as indicated in the discussion of perception reaction time and stopping sight distance. Complex conditions, problems of expectancy, high volumes and high speed require more time for the perception-reaction process. These conditions are present on arterial streets and highways, particularly in urban areas. The AASHTO Policy on Geometric Design has provided for such situations through the decision sight distance

Distinction between Stopping Sight Distance and Decision Sight Distance

The distinction between stopping sight distance and decision sight distance must be understood.

- Stopping sight distance is used when the vehicle is traveling at design speed, and one clearly discernable object or obstacle is presented in the roadway. The vehicle must decelerate to a stop at an acceptable rate to avoid the object.

- Decision sight distance applies when conflicts are numerous, conditions are complex, driver expectancies may vary, or visibility to traffic control or design features is impaired.

Most situations presented on arterials for access management require stopping sight distance at a minimum; however, decision sight distance often should be provided for safety and smoother operations.

AASHTO Decision Sight Distance

The decision sight distance as defined by the AASHTO Green Book is “the distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source or hazard in a roadway environment that may be visually cluttered, recognize the hazard or its threat potential, select an appropriate speed and path, and initiate and complete the required maneuver safely and efficiently.” According to 1990 and 1994 AASHTO, the decision sight distance requires about 6 to 10^s to detect and understand the situation and 4 to 4.5^s to perform the appropriate maneuver. For 1990 and 1994 AASTHO Greenbook, the sight distance was typically measured from a 3.5 ft. (1070 mm) height of eye to 6 in. (150 mm) object; however, this should depend on the condition that requires the decision sight distance. For example, if the condition of concern is a vehicle, such as the rear of a queue of vehicles, an object height of vehicle tail lights of 2.0 ft. (600 mm) would be appropriate. A table showing the recommended decision sight distances for various maneuvers is given in Table 5.

The standard for the 2001 AASHTO has specified eye height as 3.5 ft. (1080 mm) with a 2.0 ft. (600 mm) object for decision sight distance. This often is appropriate for decision sight distance. These eye and object heights standards are retained in the 2011 Greenbook.

Various avoidance maneuvers have been defined by AASHTO to address the variety of operating conditions that occur in traffic.

Table 5A. Decision Sight Distance (English Units)

Design Speed (mph)	Decision Sight Distance for Avoidable Maneuver, (ft.)					
	A		B	C	D	E
25	180	280	400	375	400	525
30	220	350	490	450	535	620
35	275	425	590	525	625	720
40	330	505	690	600	715	825
45	395	590	800	675	800	930
50	465	680	910	750	890	1030
55	535	775	1030	865	980	1135
60	610	875	1150	990	1125	1280
65	695	980	1275	1050	1220	1365
70	780	1090	1410	1105	1275	1445
75	875	1200	1545	1180	1365	1545
80	970	1320	1685	1260	1455	1650
	Rural	Suburban	Urban	Rural	Suburban	Urban

Table 5B. Decision Sight Distance (Metric Units)

Design Speed (km/h)	Decision Sight Distance for Avoidance Maneuver, (meters)				
	A	B	C	D	E
50	70	155	145	170	195
60	95	195	170	205	235
70	115	235	200	235	275
80	140	280	230	270	315
90	170	325	270	315	360
100	200	370	315	355	400
110	235	420	330	380	430
120	265	470	360	415	470
130	305	525	390	450	510

*Note: Avoidance Maneuvers

1. Avoidance maneuver A: Stop on rural road - $t = 3.0^s$
1a. Stop on suburban road - Assume $t = 6.0^s$
2. Avoidance maneuver B: Stop on urban road – $t = 9.1^s$
3. Avoidance maneuver C: Speed/path/direction change on rural road – $t=10.2 – 11.2^s$
4. Avoidance maneuver D: Speed/path/direction change on suburban road – $t=12.1 – 12.9^s$
5. Avoidance maneuver E: Speed/path/direction change on urban road – $t=14.0 – 14.5^s$

Source: AASHTO Greenbook, 2001.

Various operating conditions require different maneuvers in response to a situation, as well as different perception-reaction times. The perception-reaction times are shorter for the less complex rural conditions than for urban.

2011 AASHTO Policy on Geometric Design Decision Sight Distance

There are no changes in decision sight distance from the 2001 Greenbook or the 2011 Greenbook. It does state the equations to calculate decision sight distance. The equations to calculate decision sight distance for the stop avoidance maneuvers are;

$$DSD = 1.47\,Vt + 1.075\,\frac{V^2}{a} \qquad \text{(U.S. Cust.)}$$

$$DSD = 0.278\,Vt + 0.039\,\frac{V^2}{a} \qquad \text{(Metric)}$$

where DSD = decision sight distance, ft. or m,
t = premaneuver time, s, (shown in Tables 5A and 5B),
V = design speed, mph or km/h,
a = deceleration rate, 11.2 ft/sec^2 or 3.4 m/sec^2.

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