Discussion Paper No. 8.A

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

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DISCLAIMER

This background 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 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.

SPECIFIC OBJECTIVES

The specific objectives of this discussion paper are to:

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

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

4. Identify questions and issues regarding the appropriate criteria and use of stopping and decision sight distance.

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ACKNOWLEDGMENTS AND CREDITS

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OVERVIEW

Background

The safe operation of an intersection, as with all highway facilities, requires the consideration of three primary elements of the roadway: 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 stopping 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

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OVERVIEW

Content

This background paper summarizes the literature, standards and traditional knowledge on stopping and decision sight distance. The primary emphasis of this discussion is on the driver behavior and traffic operation conditions that influence the distance required for divers 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) and 1994 Edition(Metric 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, their placement and their effects on traffic stream conditions, such as traffic queues, must take account of sight distance requirements.

Adequate stopping sight distance must be provided on 100% of the street and highway system so a driver with the standard eye height may see an object of 150 mm (0.5) ft 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 determination of stopping sight distance requires the definition of 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 and local conditions and driver expectancy may require longer times and distances to accommodate normal vehicle maneuvers of lane changing, speed changes and path changes.

OVERVIEW (Continued)

Issues (Continued)

This is accommodated by the decision sight distance. Decision sight distance is applied where numerous objects, pedestrians, vehicles or design features, complex control or complex surrounding 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 for stopping versus maneuvering within the traffic stream. Consequently, there are five different cases for decision sight distance.

Decision Sight Distance Cases

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

The difference between stopping in the context of decision sight distance is that the vehicle is forced to stop for some traffic condition, such as a queue of vehicles, rather than an 150 mm (0.5 ft) object in the roadway.

In view of the complexity and variations in drivers' expectancy regarding situations associated with access management, decision sight distance is a more logical requirement for many access management measures than stopping sight distance.

OVERVIEW (Continued)

Sight Distance as an Access Management Measure

Stopping sight distance is required at all locations along the highway, to see an 150 mm (0.5 ft) object. 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 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 or approaches on multilane highways.

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 to a left turn lane or to an approach on the right.

Questions to be Answered

The selection and application of sight distance criteria 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?

2. What height of eye should be used for sight distance? What proportion of the drivers should the height of eye criterion represent?

3. Is a 150 mm (6 inch) object reasonable? Should the height of the object be different for decision sight distance? Should the height of the object be different for some situations?

OVERVIEW (Continued)

Questions to be Answered (Continued)

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

5. Should the stopping sight distance and decision sight distance be based on design speed, running speed or vary according to conditions?

6. Should the perception-reaction times specified in the AASHTO Green Book be accepted, or should they be specified according to the situation?

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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 presence or event
• Emotion	the time to decide how to react
• Volition	the time to initiate the action, for example, the time to engage the brakes

Current Design Perception-Reaction Time

Human factors research defined perception-reaction times for (1):

- 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.[2]

Wortman and Mathias (2) reported both the "surprise" and alerted 85th percentile perception reaction times. This was in an urban environment; the time was measured after the yellow indication until brake lights appeared.

The Wortman et al. research found:

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

(1) AASHTO, "Policy on Geometric Design of Streets and Highways," Washington, DC, 1984, 1990, and 1994.
(2) Wortman, R.H., and J.S. Matthaas, "Evaluation of Driver Behavior at Signalized Intersections," Transportation Research Record 904, T.R.B, Washington, D.C., 1983.

PERCEPTION-REACTION TIMES (Continued)

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. (1)	1.48	1.75
Wortman et al. (2)	1.80	2.35
Chang et al. (3)	1.90	2.50
Sivak et al. (4)	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 (4).

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

(1) Gazis, D.R, et al, "The Problem of the Amerber Signal in Traffic Flow," Operations Research 8, March-April 1960.
(2) Wortman, R.H., and J.S. Matthaas, "Evaluation of Driver Behavior at Signalized Intersections," Transportation Research Record 904, T.R.B, Washington, D.C., 1983.
(3) Chang, M.S, et al, "Timing Traffic Signal Change Intervals Based on Driver Behavior," T.R. Record 1027, T.R.B, Washington, D.C., 1985
(4) Sivak, M., et al, "Radar Measured Reaction Times of Unalerted Drivers to Brake Signals," Perceptual Motor Skills 55, 1982.

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HUMAN FACTORS

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

Visual Acuity 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.

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.

Human Mind is Single Channel 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.

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HUMAN FACTORS

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 the 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.

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 will read traffic conditions differently than unfamiliar drivers. Traffic conditions vary dramatically on major facilities; consequently, the information that drivers receive from other vehicles is constantly changing.

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.

Further, high volume and high speed conditions require longer decision times and compound any problems arising from driver expectancy.

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DRIVER EYE HEIGHT

The height of eye for design has decrease with time as the vehicle sizes and dimensions changed. The design height of eye currently is 1070 mm (3.5 ft.) (1,2). This has been reduced from 1680 mm (5.5 ft.) in the 1920s to 1150 mm (3.75 ft.) 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 (4). 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 1820 mm (71.5 in.) to 2860 mm (112.5 in.) with an average eye height of 2360 mm (93 in.). A height of eye of 2400 mm (8.0 ft.) is assumed for design (7,8).

There is some indication that the height of eye adopted by AASHTO may be reduced to 1 meter, or 3.28 ft., since the passenger car fleet has continued to decrease in height.

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OBJECT HEIGHT

The object height that has been adopted for stopping sight distance is 150 mm (6 in.) since 1965. The standards require that a driver should be able to see and stop before hitting an object of 150 mm (6 in.) in height everywhere on the roadway. This is an arbitrary value that recognizes the hazard an object of that height or larger would represent, since 30% of the compact and sub-compact vehicles could not clear a 150 mm (6 in.) object (5). It is also suggested that the 150 mm (6 in.) object height is 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 460 mm (1.5 ft.) to 610 mm (2.0 ft.) may be the 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 760 mm (2.5 ft.).

The object height at intersections is 1300 m (4.25 ft.) which is the same required for passing sight distance (1). 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 (6). 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 610 mm (2 ft.) height, with some upward diffusion of the lights. A height of object of 1150 mm (3.75 ft.) would yield a target of 150-180 mm (6-7 in.) in height, which would assure an approaching vehicle would be seen. Under conditions 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 should be either the height of the vehicle or the height of the tail-light. This would typically result in an object height of 460-760 mm (1.5-2.5 ft.). For vehicles entering the roadway at night, the height of the headlights may be used, or 610 mm (2 ft.).

Pavement sight distance should be provided on turning roadways or at locations where the alignment may take an unexpected direction. This is provided with an object height of 0.0 mm (0.0 ft.).

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VEHICLE SPEED

The speed employed in the analysis of stopping sight distance is typically the design speed in Oregon, in particular for vertical sight restrictions. AASHTO has allowed the running speed to be used, which is less than design speed, since the design coefficient of friction is for wet pavements and drivers are expected to slow on wet pavements. However, AASHTO indicates that recent data shows that drivers do not slow appreciably on wet pavement. 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 is used.

The relationship between average speed, 85th percentile speed and design speed is not well defined. However, the approximate relationship can be defined as follows. 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 (95% 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 operating speed + 5 mph

Design speed is 85th percentile speed + 5 mph.

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.

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PAVEMENT COEFFICIENT OF FRICTION

The coefficients of friction used for design on arterials or open highways in the AASHTO Green Book (1) are based on the results of a number of studies that measured the locked-wheel skid resistance on poor wet pavements. The AASHTO design values also correspond to a comfortable deceleration rate of 9.6 to 12.9 kph/sec (6 to 8 mph/second); they are shown in Table 2.

Table 2. Design Coefficients of Friction for Stopping Sight Distance

Design Speed		Running Speed		AASHTO Coefficient of Friction
30 kph	(20 mph)	32 kph	(20 mph)	0.40
50 kph	(30 mph)	45 kph	(28 mph)	0.35
65 kph	(40 mph)	58 kph	(36 mph)	0.32
80 kph	(50 mph)	71 kph	(44 mph)	0.30
100 kph	(60 mph)	84 kph	(52 mph)	0.29
115 kph	(70 mph)	93 kph	(58 mph)	0.28

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 5.6 kph/sec (3.5 mph/sec) or f = 0.16 to 8.9 kph/sec (5.5 mph/sec) or f = 0.25. Note that the coefficient of friction corresponding to a deceleration is determined from the relationship:

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

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STOPPING SIGHT DISTANCE

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

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

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

where SSD	=	required stopping sight distance, m or ft.
V	=	speed, kph or mph
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 current AASHTO Green Book provides for a minimum and a desirable stopping sight distance. The desirable stopping sight distance is provided based on the design speed and a coefficient of friction for a poor, wet pavement. The minimum stopping sight distance is provided based on the running speed and a coefficient of friction of a poor, wet pavement. A recent paper that is to be submitted to AASHTO for consideration as a new design criteria suggests using a deceleration rate of 0.34 g (3.4 m/sec^2 or 10.9 ft/sec^2) instead of the wet coefficient of function. 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 113 kph to 32 kph (70 mph to 20 mph), respectively. As indicated previously, AASHTO has found that drivers do not slow on wet pavement so the use of running speed is not appropriate. Table 3 gives the stopping sight distances for a range of design speeds. For comparison, it also gives typical emergency stopping sight distances, with short emergency reaction times of 1 sec. and wet and dry pavement conditions. The coefficient of functions for a wet pavement is assumed to be those used for stopping sight distance, and for dry pavement is assumed to be 0.6. It is interesting to note that with low beam headlights, a driver may be able to see from 37 m to 107 m (120 ft. to 350 ft.) and with high beams from 61 m to 152 m (200 ft. to 500 ft.). Thus, drivers driving faster than 88 kph (55 mph) at night are overdriving their headlights.

STOPPING SIGHT DISTANCE (Continued)

Table 3A. Design Stopping Sight Distances and Typical Emergency Stopping Distances (Metric Units)

Speed		Stopping Sight Distance, (ft.)		Typical Emergency Stopping Distance, (ft.)	
Design Speed (km/h)	Running Speed (km/h)	Desirable (2.5^s, f_{wet})	Minimum (2.5^s, f_{wet})	Wet Pave. (1^s, f_{wet})	Dry Pave. (1^s, f_{dry})
30	30	29.6	29.6	17.1	14.2
40	40	44.4	44.4	27.7	21.6
50	47	62.8	57.4	42.0	30.3
60	55	84.6	74.3	59.6	40.3
70	63	110.8	94.1	81.7	51.6
80	70	139.4	112.8	106.1	64.2
90	77	168.7	131.2	131.2	78.1
100	85	205.0	157.0	163.4	93.4
110	91	246.4	197.5	200.6	110.0
120	98	285.6	202.9	235.7	127.9

STOPPING SIGHT DISTANCE (Continued)

Table 3B. Design Stopping Sight Distances and Typical Emergency Stopping Distances (English Units)

Speed		Stopping Sight Distance, (ft.)		Typical Emergency Stopping Distance, (ft.)	
Design Speed (mph)	Running Speed (mph)	Desirable (2.5^s, f_{wet})	Minimum (2.5^s, f_{wet})	Wet Pave. (1^s, f_{wet})	Dry Pave. (1^s, f_{dry})
20	20	107	107	63	52
25	24	147	139	92	71
30	28	196	177	130	94
35	32	248	218	172	120
40	36	313	267	225	148
45	40	383	319	284	179
50	44	461	376	357	212
55	48	538	432	417	249
60	52	634	502	495	288
65	55	724	549	581	330
70	58	840	613	686	375

STOPPING SIGHT DISTANCE AND DECISION SIGHT DISTANCE

DECISION SIGHT DISTANCE

Decision Sight Distance Appropriate for Access Management

As indicated in the discussion of perception reaction time and stopping sight distance, there are many situations where stopping sight distance is not sufficient for safe and smooth operations. 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 on a poor wet pavement when one clearly discernable object or obstacle is presented in the roadway.

- Decision sight distance applies when conditions are complex, driver expectancies are different from the situation, 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 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 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. The sight distance is typically measured from a 1070 mm (3.5 ft.) height of eye to 150 mm (6 in.) object; however, this should depend on the condition that requires the decision sight distance. A table showing the recommended decision sight distances for various maneuvers is given in Table 4.

DECISION SIGHT DISTANCE (Continued)

Table 4A. Decision Sight Distance (meters)

Design Speed (km/h)	Decision Sight Distance for Avoidance Maneuver, (meters)				
	A	B	C	D	E
50	75	160	145	160	200
60	95	205	175	205	235
70	125	250	200	240	275
80	155	300	230	275	315
90	185	360	275	320	360
100	225	415	315	365	405
110	265	455	335	390	435
120	305	505	375	415	470

Table 4B. Decision Sight Distance (English units)

Design Speed (mph)	Decision Sight Distance for Avoidable Maneuver, (ft.)				
	A	B	C	D	E
30	220	500	450	500	625
40	345	725	600	725	825
50	500	975	750	900	1025
60	680	1300	1000	1150	1275
70	900	1525	1100	1300	1450

*Note: Avoidance Maneuvers

1. Avoidance maneuver A: Stop on rural road
2. Avoidance maneuver B: Stop on urban road
3. Avoidance maneuver C:Speed/path/direction change on rural road
4. Avoidance maneuver D: Speed/path/direction change on suburban road
5. Avoidance maneuver E: Speed/path/direction change on urban road

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