ELEMENTS OF DESIGN

Sight Distance

Key Ref: AASHTO's Green Book

Introduction

- The alignment of a highway or street produces a critical impact on:
  - **the environment**
  - **the community**
  - **the highway user**
- The alignment consists of a variety of design elements
- The facility (roadway) should:
  - **Serve traffic safely**
  - **Serve traffic efficiently**
  - **Be consistent with the facility's intended function**

Complementing elements

- Each alignment element should complement others to achieve a design that is:
  - **Consistent**
  - **Safe**
  - **Efficient**

Principal elements of design common to all classes of highways and streets

- **Sight distance**
- **Superelevation**
- **Traveled way widening**
- **Grades**
- **Horizontal alignment**
- **Vertical alignment**

+ Other elements of geometric design

General Considerations

- A driver's ability to see ahead is needed for safe and efficient operation of a vehicle on a highway
- ***Sight distance:*** "The length of the roadway ahead that is visible to the driver"
- Comparison between ***Railroad*** and ***Highway*** ***??***
- The designer should provide sight distance of ***sufficient length*** that ***drivers*** can ***control the operation*** of their ***vehicles*** to avoid striking an unexpected object in the traveled way.

Design Policy - Response

- Sight distance assumes drivers are traveling at:
  - **A. The posted speed limit**
  - **B. 10 mph above the speed limit**
  - **C. The 85% percentile spot speed of the facility**
  - **D. The design speed of the facility**

Categories of sight distance

1. **Sight distances needed for stopping**
   - applicable on all highways
2. **Sight distances needed for the passing of overtaken vehicles**
   - applicable only on two-lane highways
3. **Sight distances needed for decisions at complex locations**
4. **Sight distances at intersections** *(section 9.5)*

1. Stopping Sight Distance (SSD)

- **"It is the sum of the distance traversed during the brake reaction time and the distance to brake the vehicle to a stop."**
- **The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path.**
- Although **greater lengths of visible roadway are desirable**, the sight distance **at every point along a roadway should be at least that needed for a below-average driver or vehicle to stop**.

SSD: Sum of two distances

SSD = Brake reaction distance + Braking distance

1. **Brake reaction distance:** the distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied
2. **Braking distance:** the distance needed to stop the vehicle from the instant brake application begins

Brake Reaction Time

"It is the interval from the instant that the driver recognizes the existence of an obstacle on the roadway ahead that necessitates braking until the instant that the driver actually applies the brakes."

Factors affecting the reaction time needed

- **Distance to the object**
- **Vehicle speed**
- **Visual acuity of the driver**
- **Natural rapidity with which the driver reacts**
- **Atmospheric visibility**
- **Type and the condition of the roadway**
- **Nature of the obstacle**
- **Roadway environment**

Driver alertness in different scenarios

- **Driver traveling at or near the design speed VS. one traveling at a lesser speed.**

- **A driver on an urban street confronted by innumerable potential conflicts with parked vehicles, driveways, and cross streets VS. limited-access facility where such conditions should be almost nonexistent.**

Values of break reaction times from various studies

- Summarizing various studies, minimum brake reaction times for drivers could be at least **1.64 s**
  - **0.64 s for alerted drivers + 1 s for the unexpected event**
- Because the studies discussed above used simple prearranged signals, they represent the least complex of roadway conditions.
- Even under these simple conditions, it was found that some drivers took over **3.5 s** to respond.
- Actual conditions on the highway are generally more complex than those of the studies, and there is wide variation in driver reaction times.

So what value to be used for design?

- The brake reaction time used in design should be long enough to include the reaction times needed by nearly all drivers under most highway conditions.
- Studies show that a **2.5 s** brake reaction time for stopping sight situations encompasses the capabilities of most drivers, including those of older drivers.
- The recommended design criterion of **2.5 s** for brake reaction time **exceeds the 90th %ile** of reaction time for all drivers

A word of caution:

- A brake reaction time of 2.5 s is **considered adequate** for conditions that are more complex than the simple conditions used in laboratory and road tests, but it is **not adequate** for the most complex conditions encountered in actual driving.
- The **need for greater reaction time in the most complex conditions** encountered on the roadway can be found in *Section 3.2.3* (AASHTO's Green Book 2011) on "Decision Sight Distance."

e.g.

- At multiphase at-grade intersections
- At ramp terminals on through roadways

Braking Distance

- The **approximate braking distance** of a vehicle **on a level roadway traveling at the design speed** of the roadway may be determined from the following equation:

Metric	U.S. Customary
$d_B = 0.039 \frac{V^2}{a}$	$d_B = 1.075 \frac{V^2}{a}$
where:	where:
d_B = braking distance, m	d_B = braking distance, ft
V = design speed, km/h	V = design speed, mph
a = deceleration rate, m/s^2	a = deceleration rate, ft/s^2

Recommended deceleration rate for SSD

- Recommended deceleration threshold for determining stopping sight distance:

3.4 m/s² [11.2 ft/s²]

- Considered comfortable deceleration for most drivers
- Most vehicle braking systems and the tire-pavement friction levels of most roadways are capable of providing a deceleration rate of at least this threshold

Design Values

Metric	U.S. Customary
$SSD = 0.278Vt + 0.039\frac{V^2}{a}$	$SSD = 1.47Vt + 1.075\frac{V^2}{a}$
where:	where:
SSD = stopping sight distance, m	SSD = stopping sight distance, ft
V = design speed, km/h	V = design speed, mph
t = brake reaction time, 2.5 s	t = brake reaction time, 2.5 s
a = deceleration rate, m/s²	a = deceleration rate, ft/s²

Table 3-1 Stopping Sight Distance on Level Roadways

Metric					U.S. Customary				
Design Speed (km/h)	Brake Reaction Distance (m)	Braking Distance on Level (m)	Stopping Sight Distance Calculated (m)	Stopping Sight Distance Design (m)	Design Speed (mph)	Brake Reaction Distance (ft)	Braking Distance on Level (ft)	Stopping Sight Distance Calculated (ft)	Stopping Sight Distance Design (ft)
20	13.9	4.6	18.5	20	15	55.1	21.6	76.7	80
30	20.9	10.3	31.2	35	20	73.5	38.4	111.9	115
40	27.8	18.4	46.2	50	25	91.9	60.0	151.9	155
50	34.8	28.7	63.5	65	30	110.3	86.4	196.7	200
60	41.7	41.3	83.0	85	35	128.6	117.6	246.2	250
70	48.7	56.2	104.9	105	40	147.0	153.6	300.6	305
80	55.6	73.4	129.0	130	45	165.4	194.4	359.8	360
90	62.6	92.9	155.5	160	50	183.8	240.0	423.8	425
100	69.5	114.7	184.2	185	55	202.1	290.3	492.4	495
110	76.5	138.8	215.3	220	60	220.5	345.5	566.0	570
120	83.4	165.2	248.6	250	65	238.9	405.5	644.4	645
130	90.4	193.8	284.2	285	70	257.3	470.3	727.6	730
					75	275.6	539.9	815.5	820
					80	294.0	614.3	908.3	910

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate of 3.4 m/s^2 [11.2 ft/s^2] used to determine calculated sight distance.

Usage of SSD design values

- SSDs exceeding those shown in Table 3-1 should be used as the basis for design wherever practical.
- Use of longer stopping sight distances increases the margin for error for all drivers and, in particular, for those who operate at or near the design speed during wet pavement conditions.

Effect of Grade on Stopping

- When a highway is on a grade, Eq 3-1 for braking distance is modified as follows:

Metric	U.S. Customary
$d_B = \frac{V^2}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]}$	$d_B = \frac{V^2}{30\left[\left(\frac{a}{32.2}\right) \pm G\right]}$
where:	where:
d_B = braking distance on grade, m	d_B = braking distance on grade, ft
V = design speed, km/h	V = design speed, mph
a = deceleration, m/s^2	a = deceleration, ft/s^2
G = grade, rise/run, m/m	G = grade, rise/run, ft/ft

- ***G*** **is the rise in elevation divided by the distance of the run and the percent of grade divided by 100**
- **The stopping distances needed on upgrades are shorter than on level roadways; those on downgrades are longer.**

Table 3-2. Stopping Sight Distance on Grades

Metric							U.S. Customary						
Design Speed (km/h)	Stopping Sight Distance (m)						Design Speed (mph)	Stopping Sight Distance (ft)					
	Downgrades			Upgrades				Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %		3 %	6 %	9 %	3 %	6 %	9 %
20	20	20	20	19	18	18	15	80	82	85	75	74	73
30	32	35	35	31	30	29	20	116	120	126	109	107	104
40	50	50	53	45	44	43	25	158	165	173	147	143	140
50	66	70	74	61	59	58	30	205	215	227	200	184	179
60	87	92	97	80	77	75	35	257	271	287	237	229	222
70	110	116	124	100	97	93	40	315	333	354	289	278	269
80	136	144	154	123	118	114	45	378	400	427	344	331	320
90	164	174	187	148	141	136	50	446	474	507	405	388	375
100	194	207	223	174	167	160	55	520	553	593	469	450	433
110	227	243	262	203	194	186	60	598	638	686	538	515	495
120	263	281	304	234	223	214	65	682	728	785	612	584	561
130	302	323	350	267	254	243	70	771	825	891	690	658	631
							75	866	927	1003	772	736	704
							80	965	1035	1121	859	817	782

Consideration for heavy vehicles

- The recommended stopping sight distances are based on passenger car operation and do not explicitly consider design for truck operation.
- Trucks as a whole, especially the larger and heavier units, need longer stopping distances for a given speed than passenger vehicles.
- Separate stopping sight distances for trucks and passenger cars, therefore, are not generally used in highway design, WHY?

When to provide SSDs greater than the design values?

- Situation where horizontal sight restrictions occur on downgrades, particularly at the ends of long downgrades where truck speeds closely approach or exceed those of passenger cars, the greater height of eye of the truck driver is of little value.
- Although the average truck driver tends to be more experienced than the average passenger car driver and quicker to recognize potential risks, it is desirable under such conditions to provide stopping sight distance that exceeds the values in Tables 3-1 or 3-2.

Example Problems (SSD)

1. Decision Sight Distance (DSD)

Background

- Stopping sight distances are usually sufficient to allow reasonably competent and alert drivers to come to a hurried stop under ordinary circumstances.
- However, greater distances may be needed:
  - where drivers must make complex or instantaneous decisions
  - where information is difficult to perceive, or
  - when unexpected or unusual maneuvers are needed

1. Decision Sight Distance (DSD)

"The distance needed for a driver to:

- **detect an unexpected or otherwise difficult-to-perceive information source or condition in a roadway environment that may be visually cluttered**
- **recognize the condition or its potential threat**
- **select an appropriate speed and path, and**
- **initiate and complete complex maneuvers"**

When is DSD critical to provide?

Drivers need DSDs whenever there is likelihood for error in either:

- **information reception**
- **decision making**
- **control actions**

Examples of critical locations:

- interchange and intersection locations where unusual or unexpected maneuvers are needed
- changes in cross section such as toll plazas and lane drops
- areas of concentrated demand where there is apt to be "visual noise" from competing sources of information, such as:
  - roadway elements, traffic, traffic control devices, and advertising signs

DSD criteria and factors it depends on

- DSD criteria that are applicable to most situations have been developed from empirical data.
- The DSDs primarily vary depending on:
  - **location (rural or urban road)**
  - **type of avoidance maneuver needed to negotiate the location properly**

Avoidance Maneuvers

Avoidance Maneuver A: Stop on rural road—t = 3.0 s

Avoidance Maneuver B: Stop on urban road—t = 9.1 s

Avoidance Maneuver C: Speed/path/direction change on rural road—t varies between 10.2 and 11.2 s

Avoidance Maneuver D: Speed/path/direction change on suburban road—t varies between 12.1 and 12.9 s

Avoidance Maneuver E: Speed/path/direction change on urban road—t varies between 14.0 and 14.5 s

DSDs for avoidance maneuvers A and B

Metric	U.S. Customary
$DSD = 0.278Vt + 0.039\frac{V^2}{a}$	$DSD = 1.47Vt + 1.075\frac{V^2}{a}$
where:	where:
DSD = decision sight distance, m	DSD = decision sight distance, ft
t = pre-maneuver time, s (see notes in Table 3-3)	t = pre-maneuver time, s (see notes in Table 3-3)
V = design speed, km/h	V = design speed, mph
a = driver deceleration, m/s^2	a = driver deceleration, ft/s^2

DSDs for avoidance maneuvers C, D, and E

Metric	U.S. Customary
$DSD = 0.278Vt$	$DSD = 1.47Vt$
where:	where:
DSD = decision sight distance, m	DSD = decision sight distance, ft
t = total pre-maneuver and maneuver time, s (see notes in Table 3-3)	t = total pre-maneuver and maneuver time, s (see notes in Table 3-3)
V = design speed, km/h	V = design speed, mph

Table 3-3. Decision Sight Distance

Metric						U.S. Customary					
Design Speed (km/h)	Decision Sight Distance (m) Avoidance Maneuver					Design Speed (mph)	Decision Sight Distance (ft) Avoidance Maneuver				
	A	B	C	D	E		A	B	C	D	E
50	70	155	145	170	195	30	220	490	450	535	620
60	95	195	170	205	235	35	275	590	525	625	720
70	115	325	200	235	275	40	330	690	600	715	825
80	140	280	230	270	315	45	395	800	675	800	930
90	170	325	270	315	360	50	465	910	750	890	1030
100	200	370	315	355	400	55	535	1030	865	980	1135
110	235	420	330	380	430	60	610	1150	990	1125	1280
120	265	470	360	415	470	65	695	1275	1050	1220	1365
130	305	525	390	450	510	70	780	1410	1105	1275	1445
						75	875	1545	1180	1365	1545
						80	970	1685	1260	1455	1650

Avoidance Maneuver A: Stop on rural road—*t* = 3.0 s

Avoidance Maneuver B: Stop on urban road—*t* = 9.1 s

Avoidance Maneuver C: Speed/path/direction change on rural road—*t* varies between 10.2 and 11.2 s

Avoidance Maneuver D: Speed/path/direction change on suburban road—*t* varies between 12.1 and 12.9 s

Avoidance Maneuver E: Speed/path/direction change on urban road—*t* varies between 14.0 and 14.5 s

Utility of DSD values from AASHTO

- The decision sight distances in Table 3-3 may be used to:

1. **provide values for sight distances that may be appropriate at critical locations**
2. **serve as criteria in evaluating the suitability of the available sight distances at these locations**

General guidelines for DSDs

- Because of the additional maneuvering space provided, DSDs should be considered at **critical locations**
- **OR**
- **critical decision points** should be moved to locations where sufficient decision sight distance is available.
- **If it is not practical to provide decision sight distance because of horizontal or vertical curvature or if relocation of decision points is not practical** -> **proper advance warning using suitable traffic control devices**

Example Problems (DSD)

Passing Sight Distance
for Two-Lane Highways

- **PSD is the distance that drivers must be able to see along the road ahead to safely and efficiently initiate and complete passing maneuvers of slower vehicles on two-lane highways using the lane normally reserved for opposing traffic.**

Criteria for Design

- **Most roads and many streets are two-lane, two-way highways on which vehicles frequently overtake slower moving vehicles.**
- **Passing maneuvers in which faster vehicles move ahead of slower vehicles are accomplished on lanes regularly used by opposing traffic.**

- **If passing is to be accomplished without interfering with an opposing vehicle, the passing driver should be able to see a sufficient distance ahead, clear of traffic, so the passing driver can decide whether to initiate and to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver.**

- **When appropriate, the driver can return to the right lane without completing the pass if he or she sees opposing traffic is too close when the maneuver is only partially completed.**

Potential for conflicts in passing operations

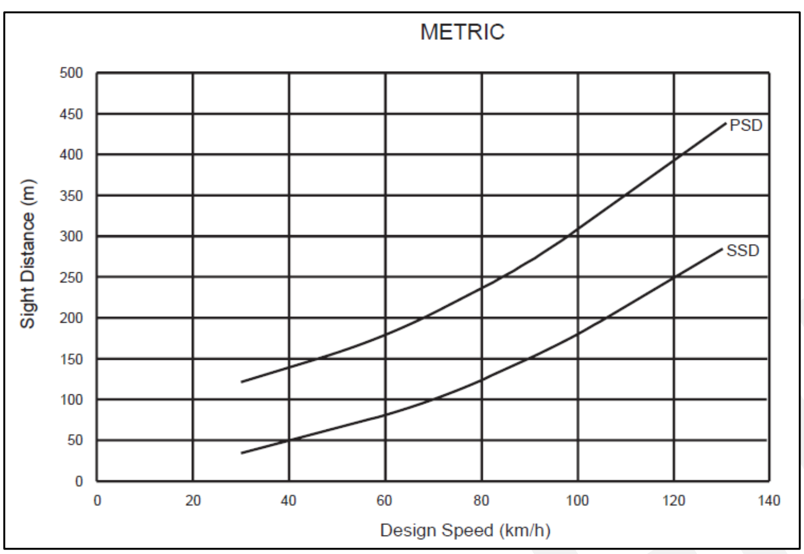
- The potential for conflicts in passing operations on two-lane highways is ultimately determined by the **judgments of drivers** that **initiate and complete passing maneuvers** in response to:

1. **the driver's view of the road ahead as provided by available passing sight distance**
2. **the passing and no-passing zone markings**

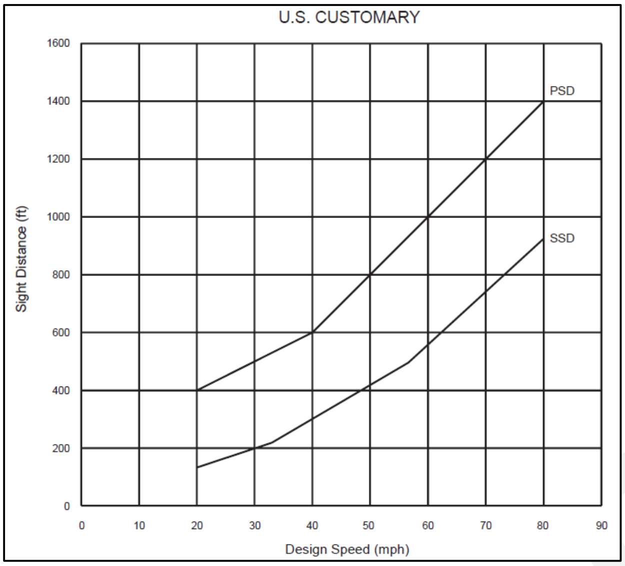
Table 3-4. Passing Sight Distance for Design of Two-Lane Highways

Metric				U.S. Customary			
Design Speed (km/h)	Assumed Speeds (km/h)		Passing Sight Distance (m)	Design Speed (mph)	Assumed Speeds (mph)		Passing Sight Distance (ft)
	Passed Vehicle	Passing Vehicle			Passed Vehicle	Passing Vehicle	
30	11	30	120	20	8	20	400
40	21	40	140	25	13	25	450
50	31	50	160	30	18	30	500
60	41	60	180	35	23	35	550
70	51	70	210	40	28	40	600
80	61	80	245	45	33	45	700
90	71	90	280	50	38	50	800
100	81	100	320	55	43	55	900
110	91	110	355	60	48	60	1000
120	101	120	395	65	53	65	1100
130	111	130	440	70	58	70	1200
				75	63	75	1300
				80	68	80	1400

Comparison of Design Values for PSD vs. SSD



Comparison of Design Values for PSD vs. SSD



More sight distance is needed to accommodate passing maneuvers on a two lane highway than for stopping sight distance that is provided continuously along the highway.

Assumptions for minimum PSDs for design of two-lane highways

- **Actual driver behavior in passing maneuvers varies widely.**
- **Minimum PSDs for design of two-lane highways incorporate certain assumptions about driver behavior.**
- **To accommodate variations in driver behavior, the design criteria for passing sight distance should accommodate the behavior of a high percentage of drivers, rather than just the average driver.**

Assumptions

1. **The speeds of the passing and opposing vehicles are equal and represent the design speed of the highway.**
2. **The passed vehicle travels at uniform speed and speed differential between the passing and passed vehicles is 19 km/h [12 mph].**
3. **The passing vehicle has sufficient acceleration capability to reach the specified speed differential relative to the passed vehicle by the time it reaches the critical position, which generally occurs about 40% of the way through the passing maneuver.**
4. **The lengths of the passing and passed vehicles are 5.8 m [19 ft], as shown for the PC design vehicle in Section 2.1.1.**

Assumptions (contd.)

5. **The passing driver's perception-reaction time in deciding to abort passing a vehicle is 1 s.**
6. **If a passing maneuver is aborted, the passing vehicle will use a deceleration rate of 3.4 m/s^2 [11.2 ft/s^2], the same deceleration rate used in stopping sight distance criteria.**
7. **For a completed or aborted pass, the space headway between the passing and passed vehicles is 1 s.**
8. **The minimum clearance between the passing and opposed vehicles at the point at which the passing vehicle returns to its normal lane is 1 s.**

PSDs for multiple passings?

- **The passing sight distance for use in design should be based on a single passenger vehicle passing a single passenger vehicle.**

- **While there may be occasions to consider multiple passings, where two or more vehicles pass or are passed, it is not practical to assume such conditions in developing minimum design criteria.**

Situation for Trucks?

- **Research has shown that longer sight distances are often needed for passing maneuvers when the passed vehicle, the passing vehicle, or both are trucks.**

- **Longer sight distances occur in design, and such locations can accommodate an occasional multiple passing maneuver or a passing maneuver involving a truck.**

Table 3-5. Minimum Passing Zone Lengths to be Included in Traffic Operational Analyses

Metric		U.S. Customary	
85th Percentile Speed or Posted or Statutory Speed Limit (km/h)	Minimum Passing Zone Length (m)	85th Percentile Speed or Posted or Statutory Speed Limit (mph)	Minimum Passing Zone Length (ft)
40	140	20	400
50	180	30	550
60	210	35	650
70	240	40	750
80	240	45	800
90	240	50	800
100	240	55	800
110	240	60	800
120	240	65	800
		70	800

Sight Distance for Multilane Highways

- **There is no need to consider passing sight distance on highways or streets that have two or more traffic lanes in each direction of travel.**
- **Passing maneuvers on multilane roadways are expected to occur within the limits of the traveled way for each direction of travel.**
- **Multilane roadways should have continuously adequate stopping sight distance, with greater-than-design sight distances preferred.**

- d_1—Distance traversed during perception and reaction time and during the initial acceleration to the point of encroachment on the left lane.
- d_2—Distance traveled while the passing vehicle occupies the left lane.
- d_3—Distance between the passing vehicle at the end of its maneuver and the opposing vehicle.
- d_4—Distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane, or 2/3 of d_2 above.

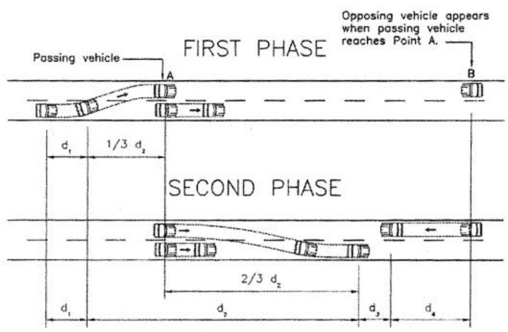


Exhibit 3-4. Elements of Passing Sight Distance for Two-Lane Highways

PSD Formulae

$D_{passing} = d_1 + d_2 + d_3 + d_4$

d_1 = distance traveled during P/R time to point where vehicle just enters the left lane

$$d_1 = 1.47 t_1 \left(u - m + \frac{a t_1}{2}\right)$$

where

t_1 = time for initial maneuver (sec)

u = average speed of passing vehicle (mph)

a = acceleration (mph/s)

m = difference between speeds of passing and passed vehicle

PSD Formulae

$D_{passing} = d_1 + d_2 + d_3 + d_4$

d_2 = distance traveled by vehicle while in left lane

$d_2 = 1.47ut_2$

where:

u = speed of passing vehicle (mph)

t_2 = time spent passing in left lane (sec)

PSD Formulae

$D_{passing} = d_1 + d_2 + d_3 + d_4$

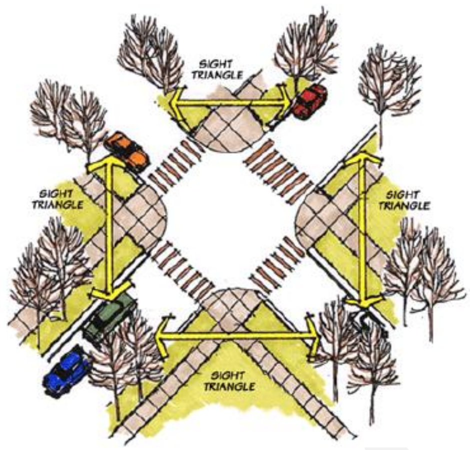
d_3 = clearance distance varies from 100 to 300 ft

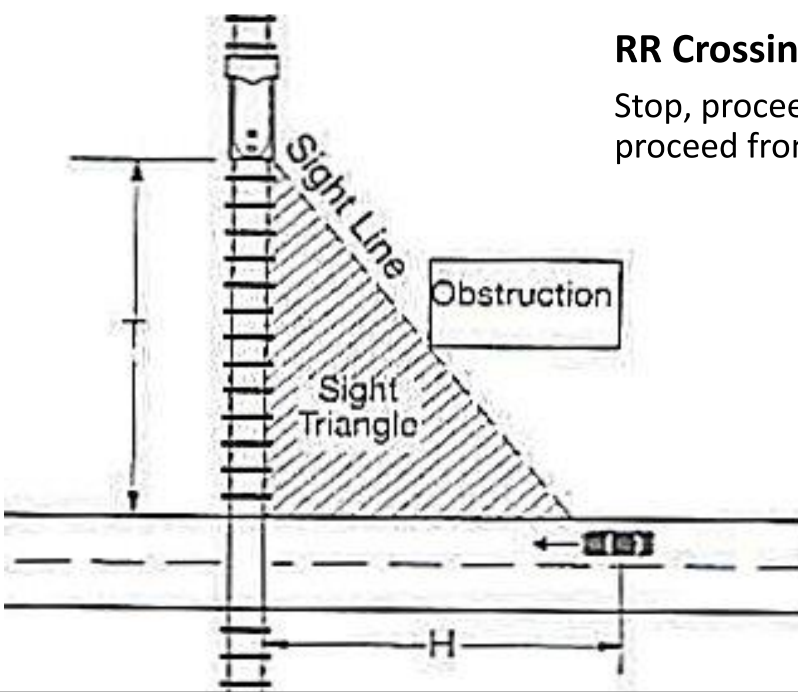
d_4 = distance traveled by opposing vehicle during passing maneuver

d_4 usually taken as 2/3 d_2

Intersection Sight Distances

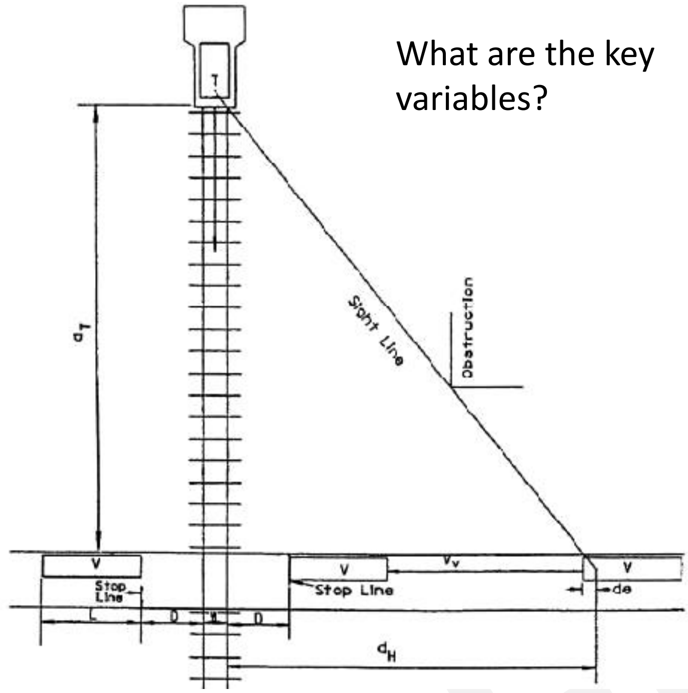
Intersection Sight Distance (turning/crossing)





RR Crossing

Stop, proceed, proceed from stop



What are the key variables?

Key issues in safe crossing

- Speeds
- Distance from front of vehicle to driver’s eye
- Distance from rail to front of vehicle
- Assumptions about PR time and braking distance
- Width of crossing
- Distance from end of vehicle after crossing
- Length of vehicle
- Acceleration capability of road vehicle
- Offset of obstruction from the road and the rail line

Etc.