Chapter 2
Human, Vehicle, and Transportation Environment Characteristics

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Outline: Chapter 2

2.1 Human-Vehicle-Environment Interaction

2.2 Driver Characteristics

2.3 Vehicle Characteristics

2.4 Road Characteristics

2.1 Human-Vehicle-Environment Interaction

Human-Vehicle-Environment Interaction

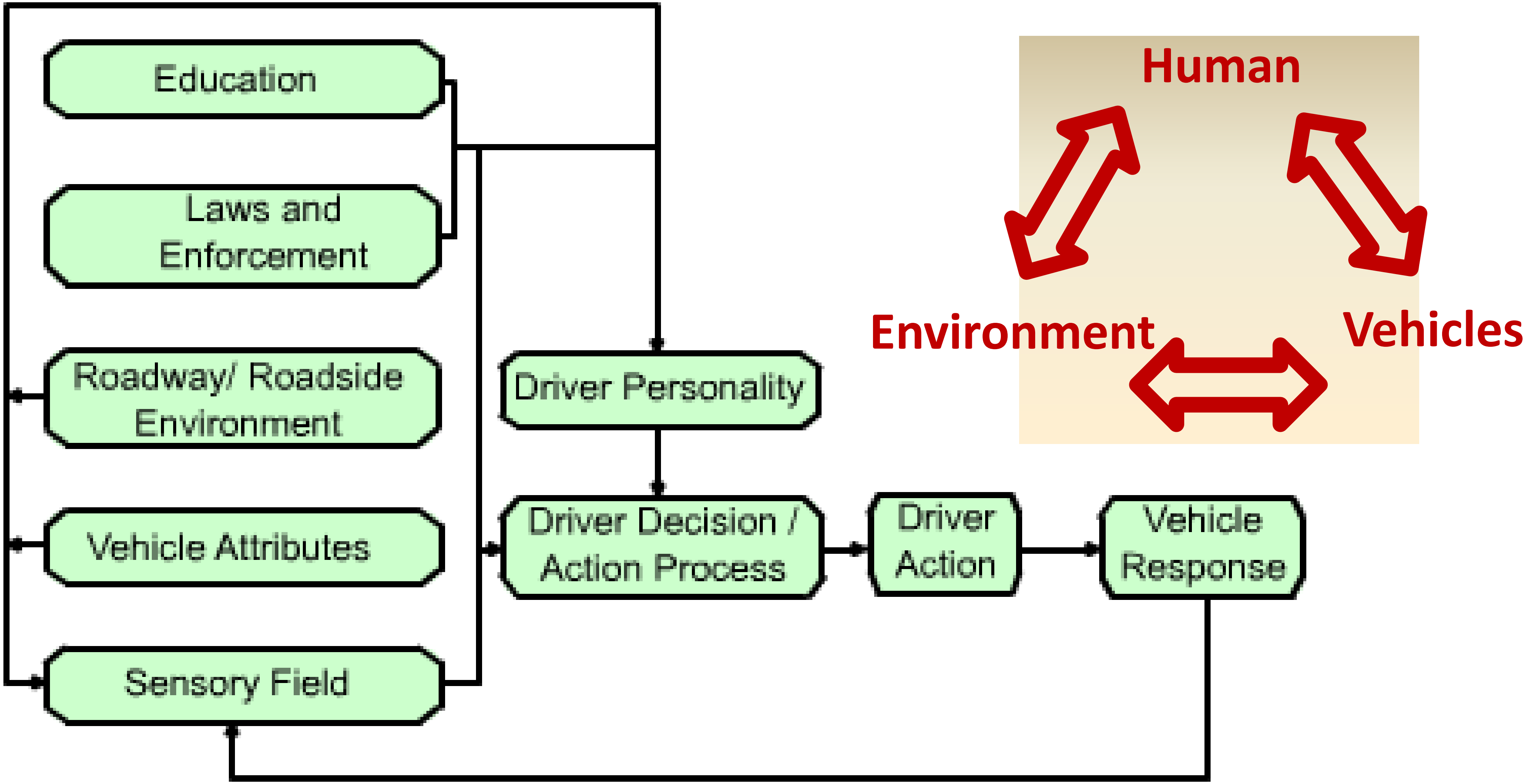


Figure 2.1 FrameWork for a Human-Vehicle-Environment Interaction Model

2.2 Driver Characteristics

Driver Characteristics

- Abilities of the driver,
  - *Different from one driver to another* due to varying levels of hearing, seeing, evaluation and reaction of the drivers.
  - *Vary for a driver* depending on time of day, psychological condition, fatigue, and influence of drugs or alcohol. :

- **For design purposes:** select criteria which is compatible with the capabilities and limitations of most drivers.
  - Average value may not be adequate
  - Usually, 85^{th} or 95^{th} percentile is selected.

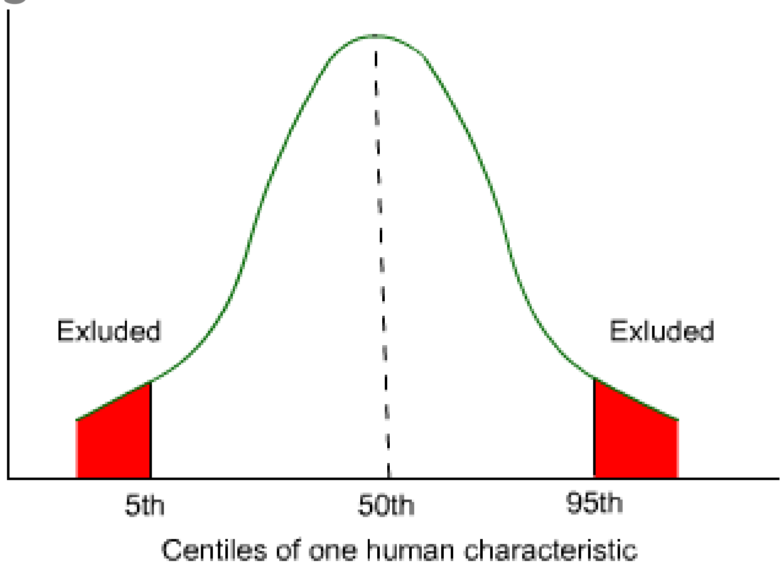


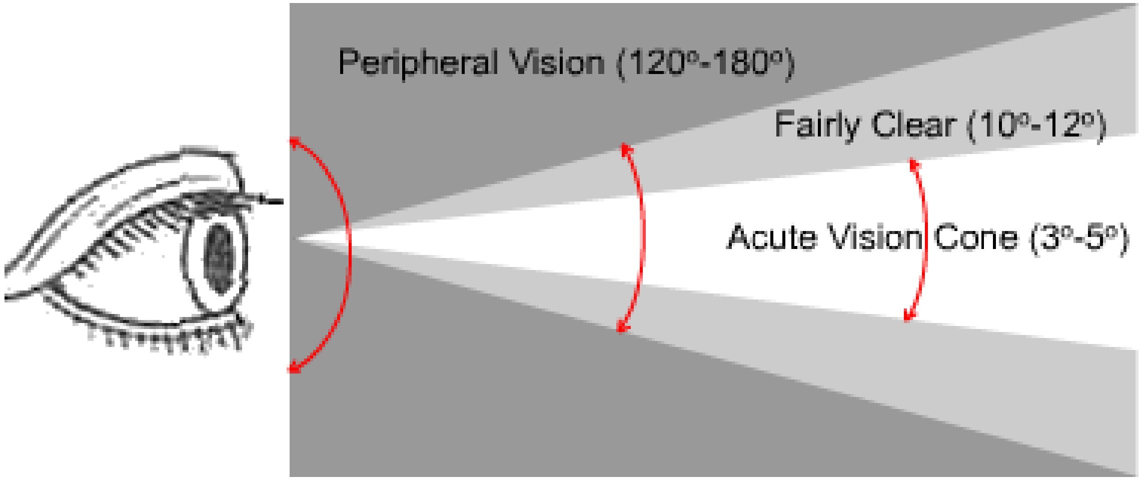
Figure 2.2 Range of Human Characteristics

Driver Characteristics

- **Human Sensory Process:**
  - ***Vision***: visual acuity (Static Dynamic)
  - Clear Vision
  - Fairly clear vision
  - Peripheral vision
  - Color vision
  - Depth perception
  - Glare vision
  - Glare recovery

    (3 sec from dark to light

    6 sec from light to dark)
  - ***Hearing:*** Hearing of sounds is important to detect warning sounds of emergency vehicles and unusual sounds of mechanical problems in the vehicle



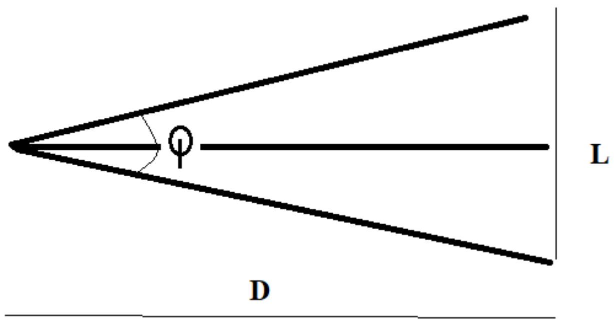
Visual Acuity

- Visual Acuity: the ability to see fine details of an object. It can be represented by the visual angle, which is the reciprocal of the smallest pattern detail in minutes of arc that can be resolved and given as:

$$\varphi = 2\arctan\left(\frac{L}{2D}\right)$$

L: diameter of the target (letter or symbol)

D: distance from the eye to target in the same units as L



$$\tan\left(\frac{\varphi}{2}\right) = \frac{L/2}{D}$$

Driver Characteristics

- **<u>Perception and Reaction Process</u>**. It can be divided into:
  - ***<u>Perception stage</u>***
  - ***<u>Identification stage</u>***
  - ***<u>Emotion stage</u>***
  - ***<u>Reaction or Volition stage</u>***

PIEV time or
<u>Perception-reaction time</u>

- **Perception –reaction time:** varies from one person to another and for the same person also.
- From 1.2 – 3.0 sec. AASHTO assumes 2.5 sec (90^{th} percentile)
  - 2.5 sec might not be adequate for complex conditions
- Braking distance, minimum sight distance, length of the amber phase at a signalized intersection.

Driver Characteristics

- **<u>Perception Reaction Time</u>**

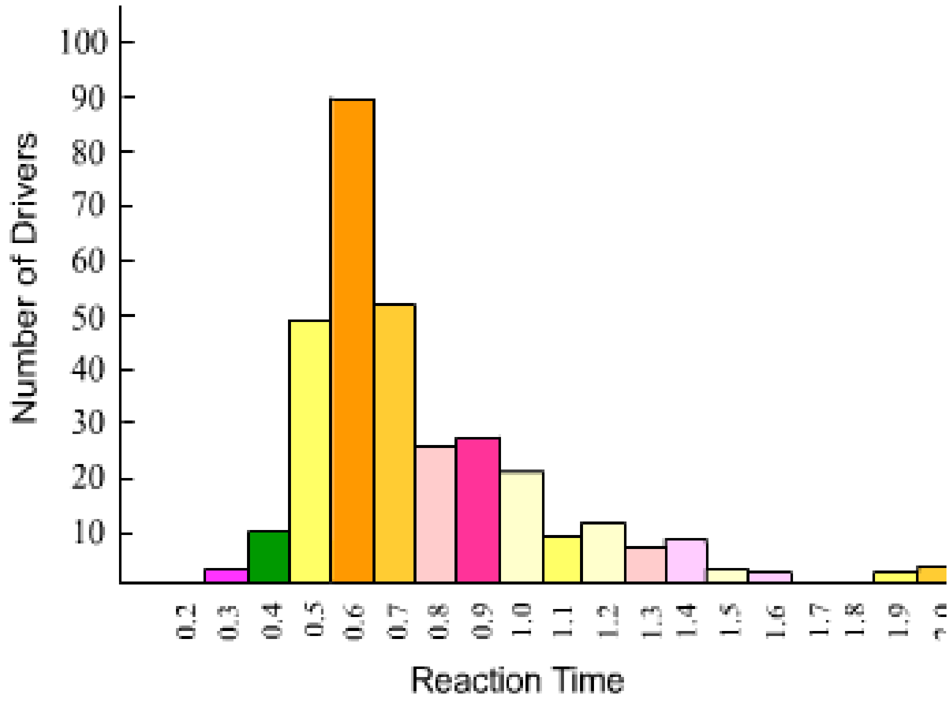


Figure 2.4 Study of Brake Reaction Time Distributior

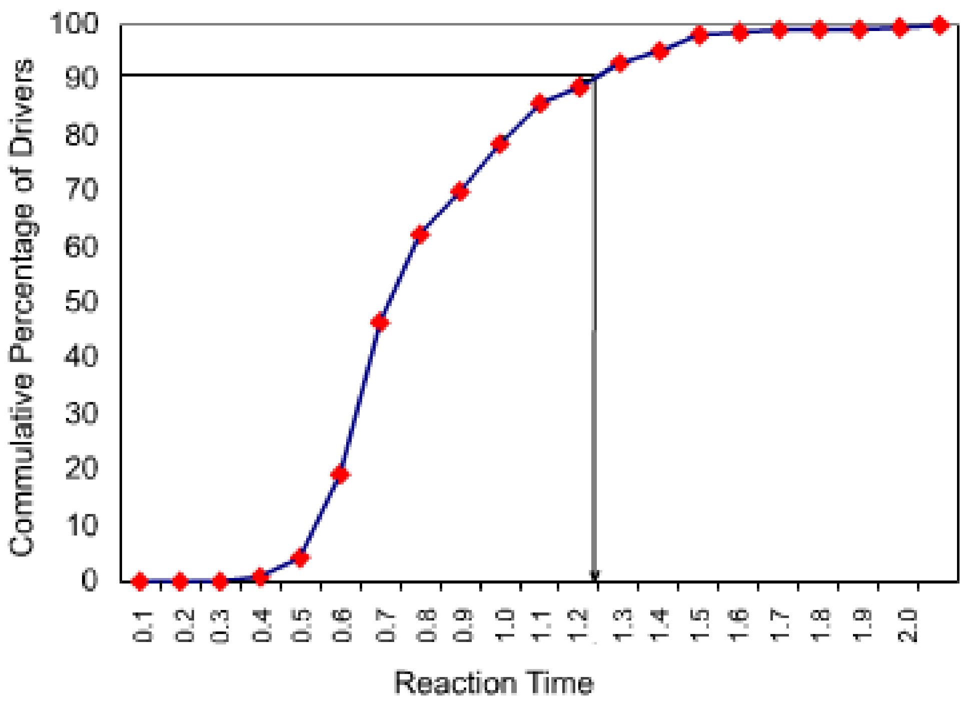


Figure 2.5 Cummulative Distribution of Brake Reaction Time

Example 3.1 Distance Traveled During Perception-Reaction Time

A driver with a perception-reaction time of 2.5 sec is driving at 65 km/h when she observes that an accident has blocked the road ahead. Determine the distance the vehicle would move before the driver could activate the brakes. The vehicle will continue to move at 65 km/h during the perception-reaction time of 2.5 sec.

Solution: **D = 0.278*u*t = 0.278*65*2.5 = 45.18 m**

- Convert km/h to m/sec:

$$65 \text{ km/h} = \left(65 \times \frac{1000}{3600}\right) = 65 \times 0.278 = 18.0 \text{ m/s}$$

- Find the distance traveled:

$$\begin{aligned} D &= vt \\ &= 18.0 \times 2.5 \\ &= 45.0 \text{ m} \end{aligned}$$

where v = velocity and t = time.

Other users' Characteristics

- **Older drivers' characteristics**:
  - *Reduced visual acuity*
  - *Reduced ability to see at night*
  - *Reduced motion range*

- **Pedestrian characteristics**:
  - *Walking speed*
  - *Elderly and handicapped pedestrians*

- **Cyclists characteristics**:

2.3 Vehicle Characteristics

Vehicle Characteristics

- A knowledge of these characteristic is necessary for proper geometric design and traffic control systems allowing for safe and smooth operations.
  - ***Static***: include the weight and size of vehicles.
  - ***Kinematic:*** involve the motion of vehicles, without considering the forces that cause the motion
  - ***Dynamic:*** involve the forces that cause the motion of vehicle

Operational Characteristics (Kinematic and Dynamic)

Vehicle Characteristics

- **Static Characteristics**

1. ***Design vehicle:*** the selected representative vehicle for the geometric design and control systems

– Its **dimensions** are important for the determination of design standards for several physical components of the highway:

  – lane width, shoulder width, parking bays length and width, and lengths of vertical curves.

– **Vehicle weight** is important for the determination of pavement depths and maximum grades.

Vehicle Characteristics

- **Static Characteristics**

Table 2.1 Physical Dimensions For Selected Key Design Vehicles

Vehicle Class	Symbol	Overall			Overhang		Other Dimensions				
		Height	Width	Length	Front	Rear	WB_1	WB_2	S	T	WB_3
Passenger Car	P	1.3	2.1	5.8	0.9	1.5	4.3	--	--	--	--
Single Unit Truck	SU	4.1	2.6	9.1	1.2	1.8	6.1	--	--	--	--
Single Unit Bus	BUS	4.1	2.6	12.1	2.1	2.4	7.6	--	--	--	--
Articulated Bus	A-BUS	3.2	2.6	18.3	2.6	2.9	5.5	--	1.2a	6.1a	--
Intermediat Semitrailer	WB-12	4.1	2.6	15.2	1.2	1.8	4.0	8.2	--	--	--
Large Semitrailer	WB-15	4.1	2.6	16.7	0.9	0.6	6.1	9.1	--	--	--
Double Botton Semitrailer	WB-18	4.1	2.6	19.9	0.6	0.9	3.0	6.1	1.2b	1.6b	6.4

Rollover the mouse

* Note: all dimentions are in meter

AASHTO has selected four general classes of vehicles: passenger cars (**P**), buses (**BUS**), trucks (**SU**), and recreational vehicles (**RV**).

American **A**ssociation of **S**tate **H**ighways and **T**ransportation **O**fficials **AASHTO**

Table 3.1 Range of State Limits on Vehicle Lengths by Type and Maximum Weight of Vehicle

Table 3.1 Range of State Limits on Vehicle Lengths by Type and Maximum Weight of Vehicle

Type	*Allowable Lengths (ft)*
Bus	35–60
Single truck	35–60
Trailer, semi/full	35–48
Semitrailer	55–85
Truck trailer	55–85
Tractor semitrailer trailer	55–85
Truck trailer trailer	65–80
Tractor semitrailer, trailer, trailer	60–105

Type	*Allowable Weights (kg)*
Single-axle	18,000–24,000
Tandem-axle	32,000–40,000
State maximum gross vehicle weight	73,280–164,000
Interstate maximum gross vehicle weight	73,280–164,000

SOURCE: Adapted from *State Maximum Sizes and Weights for Motor Vehicles*, Motor Vehicle Manufacturers' ...82.

Table 3.2 Design Vehicle Dimension

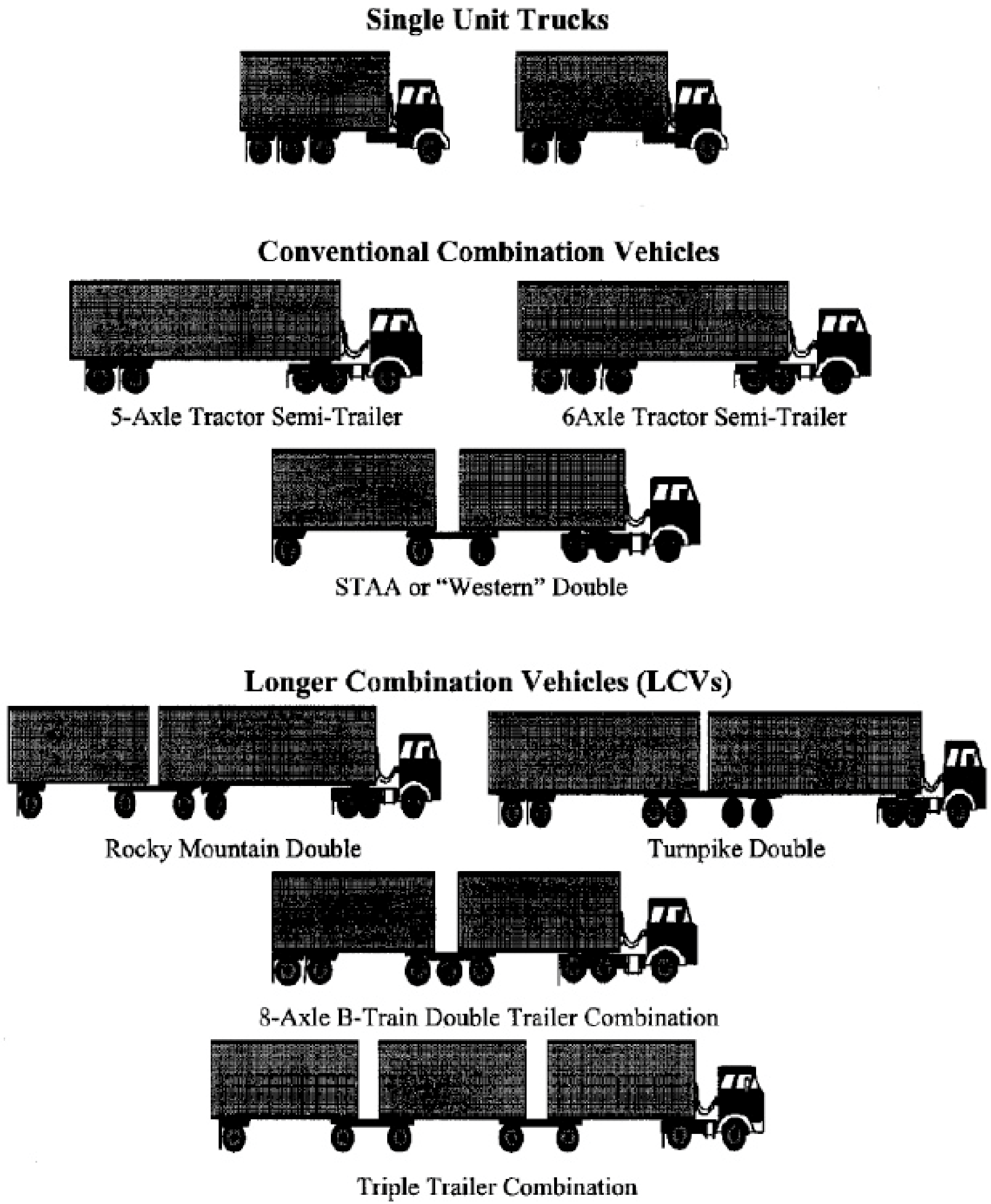
Table 3.2 Design Vehicle Dimension

		U.S. Customary											
		Dimensions (ft)											
		Overall			*Overhang*								*Typical Kingpin to Center of Rear Axle*
Design Vehicle Type	*Symbol*	*Height*	*Width*	*Length*	*Front*	*Rear*	WB_1	WB_2	*S*	*T*	WB_3	WB_4	
Passenger Car	P	4.25	7	19	3	5	11	–	–	–	–	–	–
Single-Unit Truck	SU	11–13.5	8.0	30	4	6	20	–	–	–	–	–	–
Buses													
Intercity Bus	BUS-40	12.0	8.5	40	6	6.3[a]	24	3.7	–	–	–	–	–
(Motor Coaches)	BUS-45	12.0	8.5	45	6	8.5[a]	26.5	4.0	–	–	–	–	–
City Transit Bus	CITY-BUS	10.5	8.5	40	7	8	25	–	–	–	–	–	–
Conventional School Bus (65 pass.)	S-BUS 36	10.5	8.0	35.8	2.5	12	21.3	–	–	–	–	–	–
Large School Bus (84 pass.)	S-BUS 40	10.5	8.0	40	7	13	20	–	–	–	–	–	–
Articulated Bus	A-BUS	11.0	8.5	60	8.6	10	22.0	19.4	6.2[b]	13.2[b]	–	–	–
Trucks													
Intermediate Semitrailer	WB-40	13.5	8.0	45.5	3	2.5[a]	12.5	27.5	–	–	–	–	27.5
Intermediate Semitrailer	WB-50	13.5	8.5	55	3	2[a]	14.6	35.4	–	–	–	–	37.5
Interstate Semitrailer	WB-62*	13.5	8.5	68.5	4	2.5[a]	21.6	40.4	–	–	–	–	42.5
Interstate Semitrailer	WB-65** or WB-67	13.5	8.5	73.5	4	4.5–2.5[a]	21.6	43.4–45.4	–	–	–	–	45.5–47.5
"Double-Bottom"-Semitrailer/Trailer	WB-67D	13.5	8.5	73.3	2.33	3	11.0	23.0	3.0[c]	7.0[c]	23.0	–	23.0
Triple-Semitrailer/Trailers	WB-100T	13.5	8.5	104.8	2.33	3	11.0	22.5	3.0[d]	7.0[d]	23.0	23.0	23.0
Turnpike Double-Semitrailer/Trailer	WB-109D*	13.5	8.5	114	2.33	2.5[e]	14.3	39.9	2.5[e]	10.0[e]	44.5	–	42.5
Recreational Vehicles													
Motor Home	MH	12	8	30	4	6	20	–	–	–	–	–	–
Car and Camper Trailer	P/T	10	8	48.7	3	10	11	–	5	19	–	–	–
Car and Boat Trailer	P/B	–	8	42	3	8	11	–	5	15	–	–	–
Motor Home and Boat Trailer	MH/B	12	8	53	4	8	20	–	6	15	–	–	–
Farm Tractor[f]	TR	10	8–10	16[g]	–	–	10	9	3	6.5	–	–	–

* = Design Vehicle with 48-ft trailer as adopted in 1982 Surface Transportation Assistance Act (STAA).
** = Design vehicle with 53-ft trailer as grandfathered in with 1982 Surface Transportation Assistance Act (STAA).
a = This is overhang from the back axle of the tandem axle assembly. *b* = Combined dimension is 19.4 ft and articulating section is 4 ft wide. *c* = Combined dimension is typically 10.0 ft. *d* = Combined dimension is typically 10.0 ft. *e* = Combined dimension is typically 12.5 ft. *f* = Dimensions are for a 150–200 hp tractor excluding any wagon length. *g* = To obtain the total length of tractor and one wagon, add 18.5 ft to tractor length. Wagon length is measured from front of drawbar to rear of wagon, and drawbar is 6.5 ft long.

- WB_1, WB_2, WB_3, and WB_4 are the effective vehicle wheelbases, or distances between axle groups, starting at the front and working towards the back of each unit.
- S is the distance from the rear effective axle to the hitch point or point of articulation.
- ... he center of the next axle or center of tandem axle assembly.

... : American Association of State Highway and Transportation Officials, Washington, D.C., 2004.


Single Unit Trucks
Conventional Combination Vehicles
5-Axle Tractor Semi-Trailer
6Axle Tractor Semi-Trailer
STAA or "Western" Double
Longer Combination Vehicles (LCVs)
Rocky Mountain Double
Turnpike Double
8-Axle B-Train Double Trailer Combination
Triple Trailer Combination

s of Trucks

Vehicle Characteristics

- **Static Characteristics**

  2. ***Turning Radii:*** Minimum turning radii at low operating speeds (up to 10 mph) are dependent mainly on the dimensions of the vehicle.

     – This defines the minimum turning path of the vehicle as well as the width of the traveled way

Minimum turning radii for WB-18 design vehicle

Figure 3.3 Minimum Turning Path for Interstate Semitrailer (WB-20 [WB-65 and WB-67]) Design

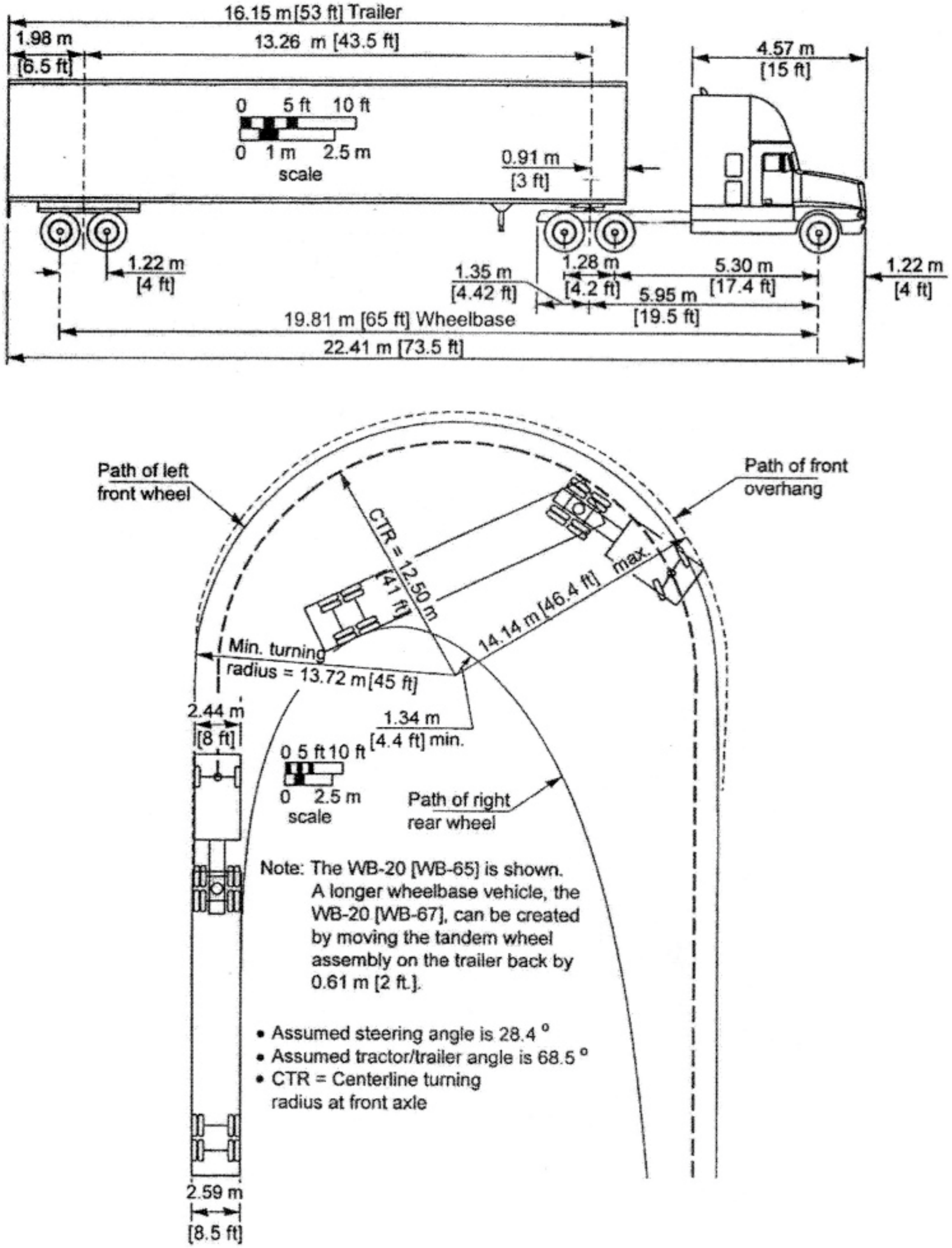


Figure 3.3 Minimum Turning Path for Interstate Semitrailer (WB-20 [WB-65 and WB-67]) Design Value

SOURCE: From Texas State Department of Highways and Public Transportation, reprinted in *A Policy on Geometric Design ... Streets,* American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used by

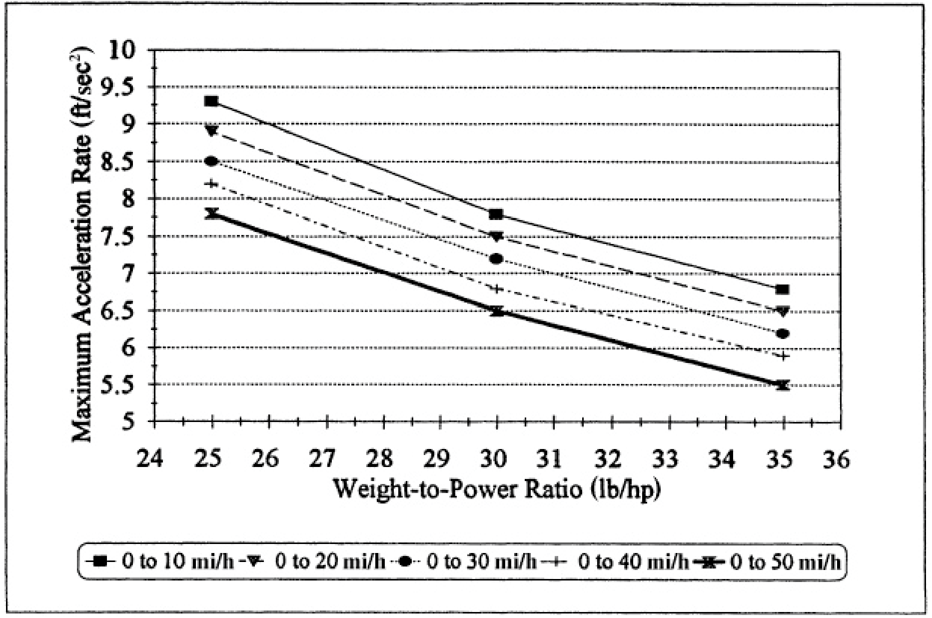
Vehicle Characteristics

- **Kinematic Characteristics**
  - The primary element among kinematic characteristics is the acceleration capability of the vehicle.
  - **Acceleration and speed** is important in:
    - Traffic operations such as passing maneuvers and gap acceptance,
    - The geometric design of acceleration, creeper and passing lanes.
    - The lower the speed, the higher the acceleration rate that can be obtained.

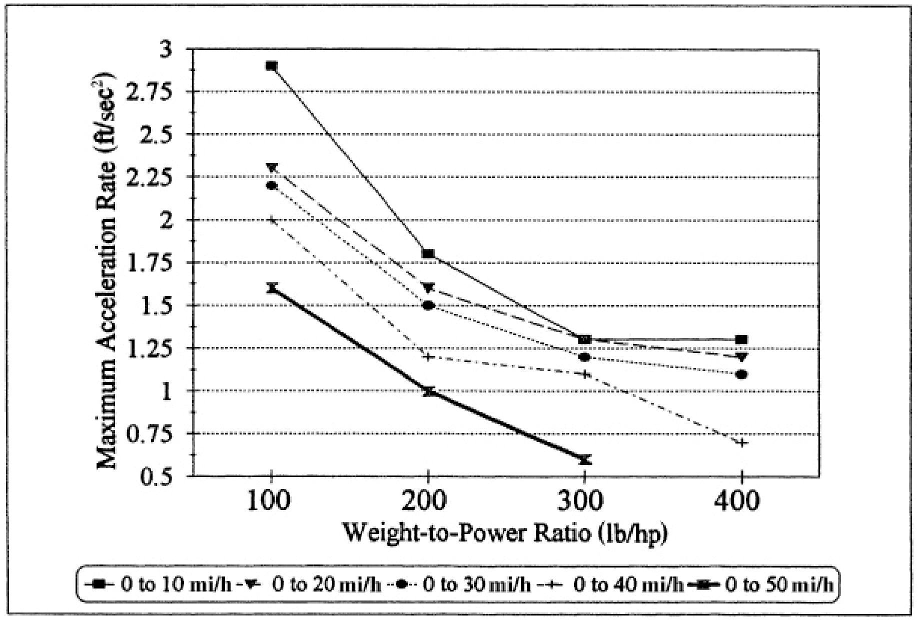
Acceleration rate (a) $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$

Acceleration distance (Da) $D_a = vt + \frac{1}{2} a t^2$

Figure 3.4 Acceleration Capabilities of Passenger Cars and Tractor Semitrailers on Level Roads



(a) Passenger Cars



(b) Tractor-Semitrailers

Figure 3.4 Acceleration Capabilities of Passenger Cars and Tractor-Semitrailers on Level Roads

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Vehicle Characteristics

- **Dynamic Characteristics**

1. **Resistance:** While a vehicle is in motion, the following forces act on it:
   - **Air resistance.**
   - **Grade resistance.**
   - **Rolling resistance.**
   - **Curve resistance.**

- Air Resistance

$$R_a = 0.5 \frac{(0.077 pC_D A u^2)}{g} \tag{3.13}$$

where

R_a = air resistance force (kg)
p = density of air (1.227 kg/m^3) at sea level; less at higher elevations
C_D = aerodynamic drag coefficient (current average value for passenger cars is 0.4; for trucks, this value ranges from 0.5 to 0.8, but a typical value is 0.5)
A = frontal cross-sectional area (m^2)
u = vehicle speed (km/h)
g = acceleration of gravity (9.81 m/sec^2)

- Air Resistance

$$R_a = 0.5\,\frac{(2.15 p C_D A u^2)}{g}$$

where

R_a = air resistance force (lb)
p = density of air (0.0766 lb/ft^3) at sea level; less at higher elevations
C_D = aerodynamic drag coefficient (current average value for passenger cars is 0.4; for trucks, this value ranges from 0.5 to 0.8, but a typical value is 0.5)
A = frontal cross-sectional area (ft^2)
u = vehicle speed (mi/h)
g = acceleration of gravity (32.2 ft/sec^2)

- Grade Resistance
  - grade resistance = weight x grade,
- in decimal

- Rolling Resistance

The rolling resistance force for passenger cars on a smooth pavement can be determined from the relation

$$R_r = (C_{rs} + 0.077 C_{rv} u^2) W \qquad (3.14)$$

R = rolling resistance force (kg)
C_{rs} = constant (typically 0.012 for passenger cars)
C_{rv} = constant (typically 7×10^{-6} s^2/m^2 for passenger cars)
u = vehicle speed (km/h)
W = gross vehicle weight (kg)

For trucks, the rolling resistance can be obtained from

$$R_r = (C_a + 0.278 C_b u) W \qquad (3.15)$$

where

R_r = rolling resistance force (kg)
C_a = constant (typically 0.02445 for trucks)
C_b = constant (typically 0.00147 s/m for trucks)
u = vehicle speed (km/h)

- Rolling Resistance

$$R_r = (C_{rs} + 2.15 C_{rv} u^2) W$$

where

R = rolling resistance force (lb)
C_{rs} = constant (typically 0.012 for passenger cars)
C_{rv} = constant (typically 0.65×10^{-6} sec^2/ft^2 for passenger cars)
u = vehicle speed (mi/h)
W = gross vehicle weight (lb)

For trucks, the rolling resistance can be obtained from

$$R_r = (C_a + 1.47 C_b u) W$$

where

R_r = rolling resistance force (lb)
C_a = constant (typically 0.02445 for trucks)
C_b = constant (typically 0.00044 sec/ft for trucks)
u = vehicle speed (mi/h)
W = gross vehicle weight (lb)

- Curve Resistance

$$R_c = 0.5 \frac{(0.077 u^2 W)}{gR} \tag{3.16}$$

where

R_c = curve resistance (kg)
u = vehicle speed (km/h)
W = gross vehicle weight (kg)
g = acceleration of gravity (9.81 m/sec^2)
R = radius of curvature (m)

- Curve Resistance

$$R_c = 0.5\frac{(2.15u^2W)}{gR}$$

where

R_c = curve resistance (lb)
u = vehicle speed (mi/h)
W = gross vehicle weight (lb)
g = acceleration of gravity (32.2 ft/sec^2)
R = radius of curvature (ft)

- Power Requirements

$$P = \frac{0.278Ru}{76}$$

- *P :* horsepower delivered (hp)
- R : sum of resistance to motion (kg)
- u : speed of vehicle in Km/hr

- Power Requirements

$$P = \frac{1.47\ Ru}{550}$$

where

P = horsepower delivered (hp)
R = sum of resistance to motion (lb)
u = speed of vehicle (mi/h)

Figure 3.6 Forces Acting on a Moving Vehicle

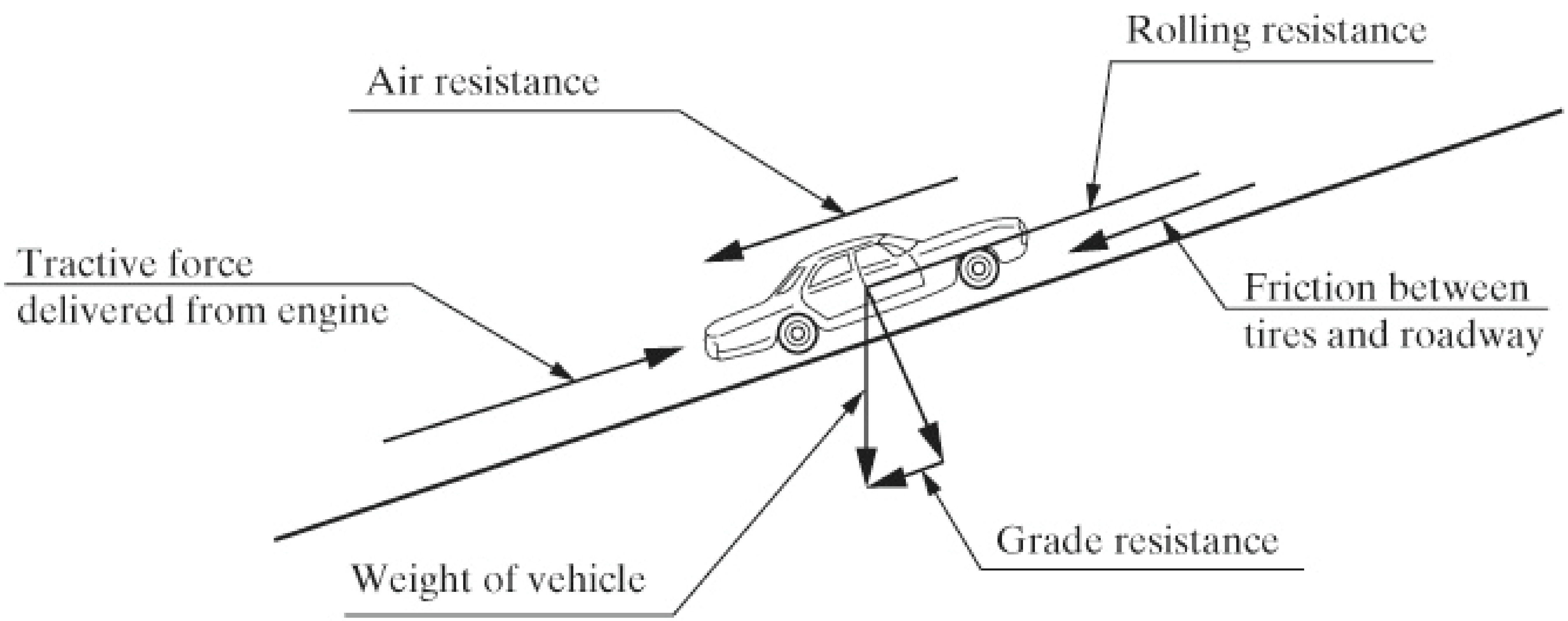


Figure 3.6 Forces Acting on a Moving Vehicle

Vehicle Characteristics

- **Dynamic Characteristics**

1. **Resistance:**

Example

Example 3.4 Vehicle Horsepower Required to Overcome Resistance Forces

Determine the horsepower produced by a passenger car traveling at a speed of 105 km/h on a straight road of 5% grade with a smooth pavement. Assume the weight of the car is 1800 kg and the cross-sectional area of the car is 3.8 m^2.

Solution: The force produced by the car should be at least equal to the sum of the acting resistance forces.

$$R = (\text{air resistance}) + (\text{rolling resistance}) + (\text{upgrade resistance})$$

Note: There is no curve resistance since the road is straight.

- Use Eq. 3.13 to determine air resistance.

$$R_a = 0.5\left(\frac{0.077\,pC_D A u^2}{g}\right)$$

$$= 0.5\,\frac{0.077 \times 1.277 \times 0.4 \times 3.8 \times 105 \times 105}{9.81}$$

$$= 80.7 \text{ kg}$$

- Use Eq. 3.14 to determine rolling resistance.

$$
\begin{aligned}
R_r &= (C_{rs} + 0.077 C_{rv} u^2)(1800) \\
&= (0.012 + 0.077 \times 7 \times 10^{-6} \times 105 \times 105) \times 1800 \\
&= (0.012 + 0.006) \times 1800 \\
&= 0.018 \times 1800 \\
&= 32.3\,\text{kg}
\end{aligned}
$$

$$\text{Grade resistance} = 1800 \times \frac{5}{100} = 90\,\text{kg}$$

- Determine total resistance.

$$R = R_a + R_r + \text{grade resistance} = 80.7 + 32.3 + 90 = 203\,\text{kg}$$

- Use Eq. 3.17 to determine horsepower produced.

$$
\begin{aligned}
P &= \frac{0.278 Ru}{76} \\
&= \frac{0.278 \times 203 \times 105}{76} \\
&= 78\,\text{hp}
\end{aligned}
$$

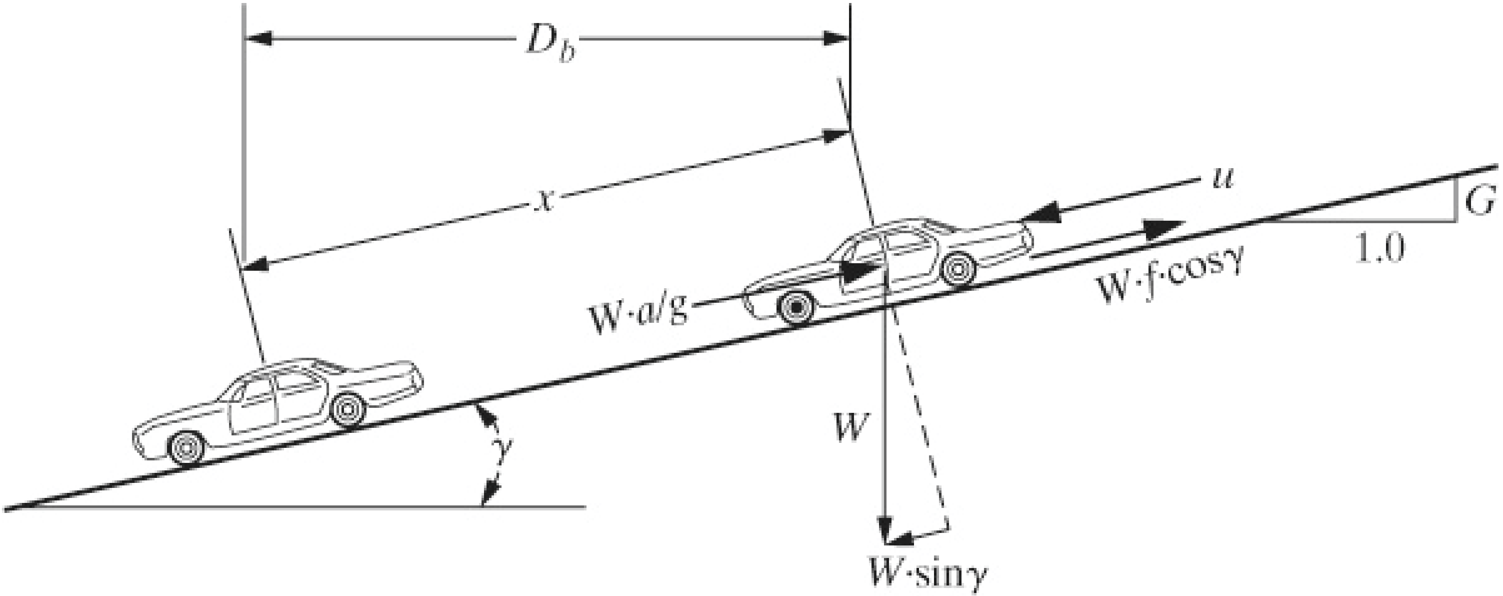
Vehicle Characteristics

- **Dynamic Characteristics**

2. **Braking:** the distance moved while decelerating

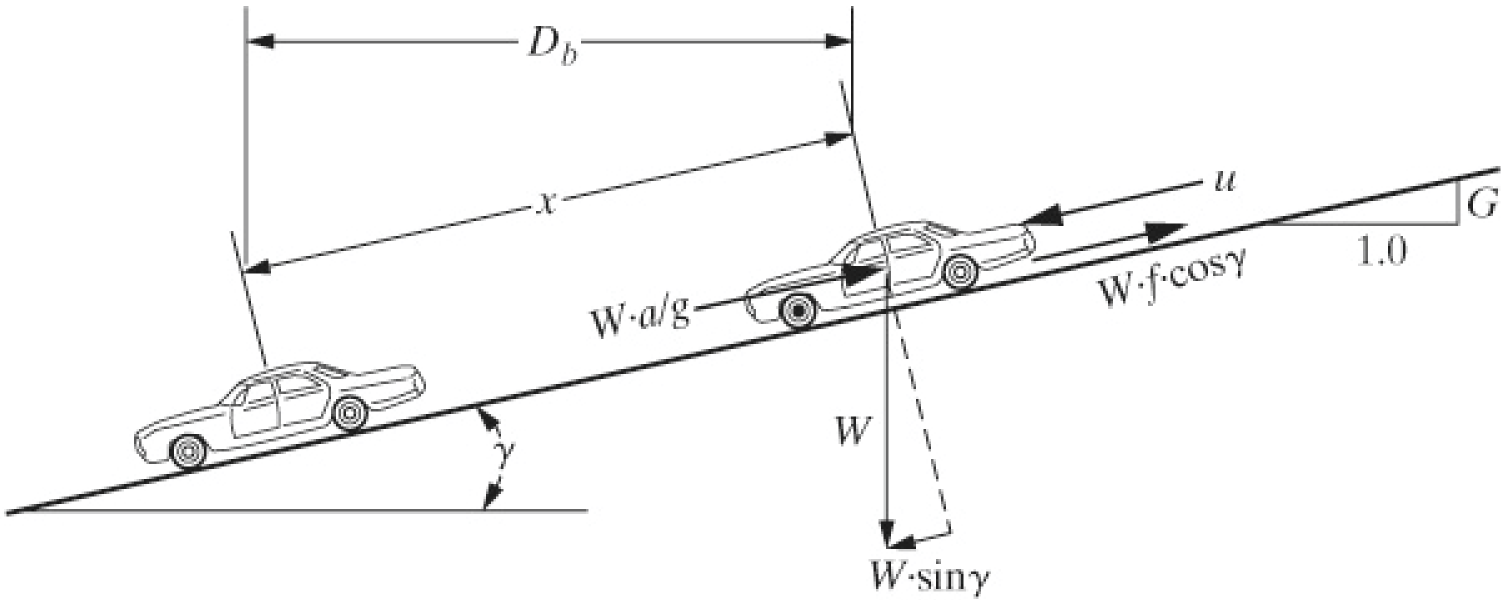
   – **Stopping Distance S or SSD.**

Figure 3.7 Forces Acting on a Vehicle Braking on a Downgrade



W = weight of vehicle
f = coefficient of friction
g = acceleration of gravity
a = vehicle acceleration
u = speed when brakes applied
D_b = braking distance
γ = angle of incline
G = tan γ (% grade/100)
x = distance traveled by the vehicle along the road during braking

Braking on a Downgrade



$$\text{Frictional force on the vehicle} = Wf\cos\gamma$$

The force acting on the vehicle due to deceleration is Wa/g.

$$\Sigma f = ma,$$

$$W\sin\gamma - Wf\cos\gamma = \frac{Wa}{g}$$

$$D_b = x\cos\gamma,$$

$$D_b = \frac{u^2}{2g(f - \tan\gamma)} \quad \rightarrow \quad D_b = \frac{u^2}{2g(f - G)}$$

f=a/g
a=11.2 ft/sec^2
G = 32.2 ft/sec^2
a/g = 0.35

$$D_b = \frac{u^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$D_b = \frac{u_1^2 - u_2^2}{30\left(\frac{a}{g} \pm G\right)}$$

$$S(\text{ft}) = 1.47ut + \frac{u^2}{30\left(\frac{a}{g} \pm G\right)}$$

Example 3.6 Exit Ramp Stopping Distance

A motorist traveling at 105 km/h on an expressway intends to leave the expressway using an exit ramp with a maximum speed of 56 km/h. At what point on the expressway should the motorist step on her brakes in order to reduce her speed to the maximum allowable on the ramp just before entering the ramp, if this section of the expressway has a downgrade of 3%?

Solution: Use Eq. 3.26.

$$D_b = \frac{u_1^2 - u_2^2}{254\left(\frac{a}{g} - 0.03\right)}$$

$$a/g = 3.41/9.81 = 0.35$$

$$D_b = \frac{105^2 - 56^2}{254(0.35 - 0.03)} = 97.06 \text{ m}$$

The brakes should be applied at least 97.06 m from the ramp.

Example 3.7 Distance Required to Stop for an Obstacle on the Roadway

A motorist traveling at 89 km/h down a grade of 5% on a highway observes a crash ahead of him, involving an overturned truck that is completely blocking the road.

If the motorist was able to stop his vehicle 9 m from the overturned truck, what was his distance from the truck when he first observed the crash? Assume perception-reaction time = 2.5 sec.

Solution:

- Use Eq. 3.27 to obtain the stopping distance.

$$\frac{a}{g} = 0.35$$

$$\begin{aligned} S &= 0.278ut + \frac{u^2}{254(0.35 - 0.05)} \\ &= 0.278 \times 89 \times 2.5 + \frac{89^2}{254 \times 0.30} \\ &= 61.86 + 103.95 \\ &= 165.81 \text{ m} \end{aligned}$$

- Find the distance of the motorist when he first observed the crash.

$$S + 9 = 174.81 \text{ m}$$

Vehicle Characteristics

- **Dynamic Characteristics**

3. Motion on horizontal curves (Minimum curve radius):

When a vehicle is moving around a circular curve:

- **Centrifugal force**: It is an inward radial force acting on the vehicle.

$$F_c = \frac{W a_c}{g}$$

a_c = acceleration for curvilinear motion = u^2/R (R = radius of the curve)
W = weight of the vehicle
g = acceleration of gravity

- **Superelevation:** The inclination of the roadway toward the center of the curve
  - Highway location, weather conditions, the distribution of slow moving traffic
  - In rural areas with no snow (max 0.1), snow and ice area (0.08 ~0.1), in urban areas (max 0.08)

- **Dynamic Characteristics**

3. **Minimum curve radius:** When a vehicle is moving around a circular curve:

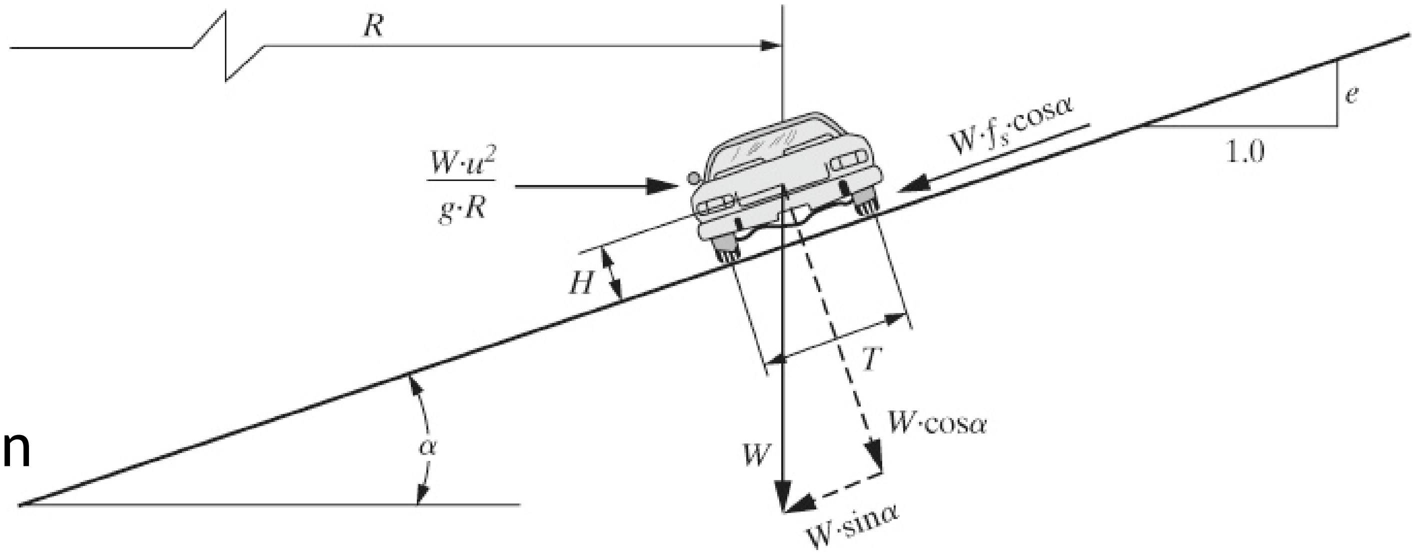


Figure 3.8 Forces Acting on a Vehicle Travelling on a Horizontal Curve Section of a Road

W = weight of vehicle
f_s = coefficient of side friction
g = acceleration of gravity
u = speed when brakes applied
R = radius of curve
α = angle of incline
$e = \tan \alpha$ (rate of superelevation)
T = track width
H = height of center of gravity

...cting on a Vehicle Traveling on a Horizontal Curve Section of a Road

Vehicle Characteristics

- **Dynamic Characteristics**

3. **Minimum curve radius:** equilibrium with respect to the incline road surface

$$\frac{W u^2}{gR}\cos\alpha = W\sin\alpha + W f_s \cos\alpha$$

$$R = \frac{u^2}{g(e + f_s)}$$

assuming g = 32.2 ft/sec2 and u in mi/hr

Rmin = $(u^2)/((127[e+fs]))$

$$R = \frac{u^2}{15(e + f_s)}$$

Vehicle Characteristics

- **Dynamic Characteristics**

3. Minimum curve radius:

Table 3.3 Coefficient of Side Friction for Different Design Speeds

Design Speed (mi/h)	*Coefficients of Side Friction, f_s*
30	0.20
40	0.16
50	0.14
60	0.12
70	0.10

SOURCE: Adapted from *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used by permission.

Example 3.9 Minimum Radius of a Highway Horizontal Curve

An existing horizontal curve on a highway has a radius of 142 m, which restricts the posted speed limit on this section of the road to only 61.5% of the design speed of the highway. If the curve is to be improved so that its posted speed will be the design speed of the highway, determine the minimum radius of the new curve. Assume that the rate of superelevation is 0.08 for both the existing curve and the new curve to be designed.

Solution:

- Use Eq. 3.34 to find the posted speed limit on the existing curve. Since the posted speed limit is not known, assume f_s is 0.16.

$$R = \frac{u^2}{127(e + f_s)}$$

$$142 = \frac{u^2}{127(0.08 + 0.16)}$$

$$u = 65.79 \text{ km/h}$$

Vehicle Characteristics

- **Dynamic Characteristics**

3. Minimum curve radius:

Example:

Example 2.1: Superelevation

Find the superelevation to be provided for a horizontal curve with radius of 400m. Consider the design speed = 100 kph and f = 0.15 .

Solution:

$$R = \frac{V^2}{g(e+f)}$$

$$e = \frac{V^2}{g \times R} - f$$

then

$$\frac{100 \times \left(\frac{1000}{60 \times 60}\right)^2}{\ldots} - 0.15 = 0.0466$$

2.4 Road Characteristics

Road- Vehicle Characteristics

- **Sight Distance:** the length of the roadway a driver can see ahead at any particular time.
- A minimum sight distance is to be provided to allow the driver to make the necessary maneuvers without being involved in an accident (assuming that the driver is travelling with the design speed).
- Two types:
  - **Stopping Sight Distance (SSD):**

$$SSD = d_{pr} + d_b \qquad \text{Equation 2.8}$$

$$d_{pr} = u.t \qquad \text{Equation 2.9}$$

$$d_b = \frac{u^2}{2g(f \pm G)} \qquad \text{Equation 2.10}$$

where:

SSD is the stopping sight distance.
d_{pr} is the distance traveled during perception-reaction time
d_b is the distance traveled during braking
t is the perception reaction time
u is the vehicle speed
g is acceleration of gravity
f is the vehicle coefficient of friction

Road- Vehicle Characteristics

- **<u>Sight Distance:</u>**
  - **Passing Sight Distance (PSD):**
    - The minimum sight distance to be provided to allow a driver to overtake (pass) safely on a two-lane two-way roadway.
      - Necessary to avoid collisions with opposite vehicles when overtaking.
      - Allow the driver to successfully abort passing maneuver.

Road- Vehicle Characteristics

- **Sight Distance:**
  - **Passing Sight Distance (PSD):**
    - Assumptions
      - The passing and passed vehicles are traveling at the same speed before beginning the passing maneuver.
      - The passed vehicle continues traveling at a uniform speed.
      - The passing driver requires some time to decide whether to overtake the passing maneuver.
      - During passing, speed difference between passing and passed vehicle is 10mi/h (15km/h).
      - Suitable clearance exists between the passing vehicle and ar opposite vehicle.

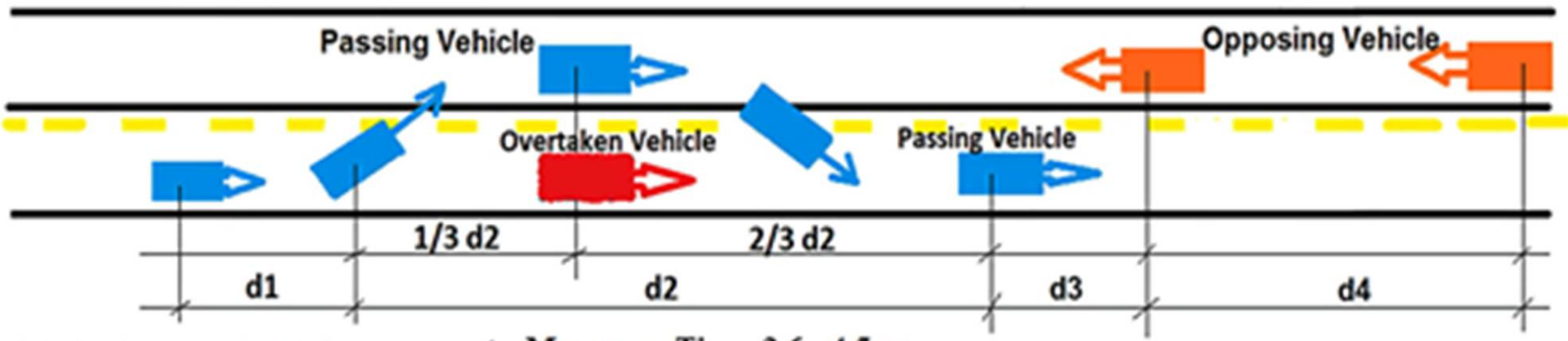
d1 : Initial Maneuver Distance

d2 : Left Lane Distance

d3 : Clearance Distance

d4 : Opposing Veh Distance

$$PSD = d1 + d2 + d3 + d4$$



$d1 = 0.278 t_i \, [v - m + (a t_i / 2)]$

$d2 = 0.278 v t_2$

$d3 = 30.0 - 90.0 \, m$

$d4 = 2/3 \, d2$

t_i : Maneuver Time, 3.6 - 4.5 sec

v : Speed of Passing Vehicle, km/h

a : Acceleration Rate, 2.25 - 2.41 km/h/sec

m : Differential Speed, km/h

t_2 : Left Lane Time, 9.3 - 11.3 sec

Road- Vehicle Characteristics

- **Sight Distance:**
  - Passing Sight Distance (PSD):

$PSD = d_1 + d_2 + d_3 + d_4$ Equation 2.11

$d_1 = t_1 \cdot (u - m + \frac{at_1}{2})$ Equation 2.12

where:

t_1 is the time for initial maneuver

u is the average speed of the passing vehicle

m is the difference in speed of passing and passed vehicle

a is the average acceleration

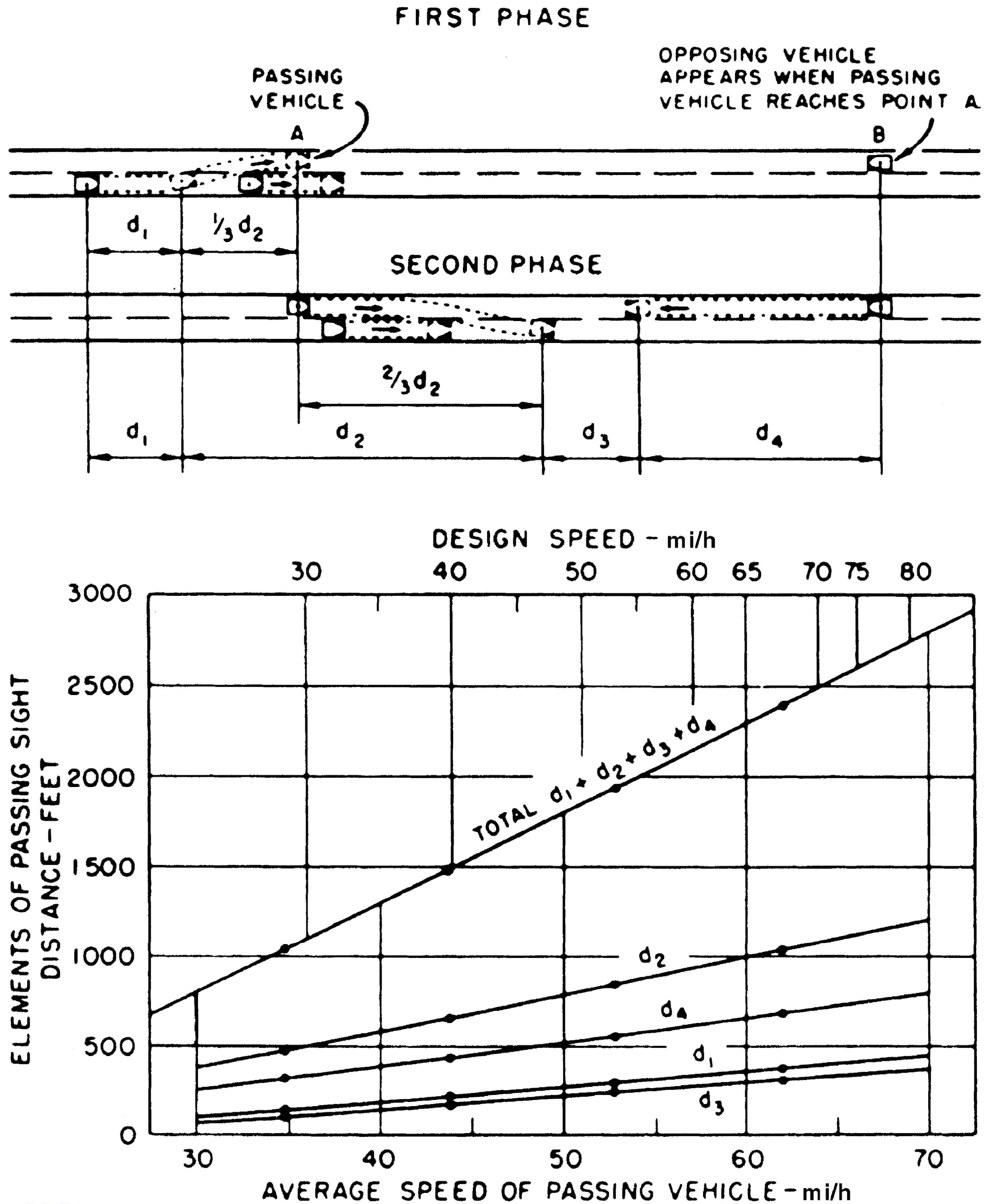
$d_2 = u\, t_2$ Equation 2.13

where:

t_2 is the time during while the passing vehicle occupies the left lane

- d_3 is the clearance distance between the passing vehicle and the opposing vehicle at the completion of the passing maneuver, range from 110-300 ft (35-90 m).
- d_4 is the distance traversed by the opposing vehicle during two thirds of the time the passing vehicle is in the left lane (i.e. equals (2/3) d2).

Figure 3.9 Elements of and Total Passing Sight Distance on Two-Lane Highways



.9 Elements of and Total Passing Sight Distance on Two-Lane Highways

Table 3.6 Components of Safe Passing Sight Distance on Two-Lane Highways

Component	*Speed Range in mi/h (Average Passing Speed in mi/h)* 30–40 (34.9)	40–50 (43.8)	50–60 (52.6)	60–70 (62.0)
Initial maneuver:				
a = average acceleration (mi/h/sec)[a]	1.40	1.43	1.47	1.50
t_1 = time (sec)[a]	3.6	4.0	4.3	4.5
d_1 = distance traveled (ft)	145	216	289	366
Occupation of left lane:				
t_2 = time (sec)[a]	9.3	10.0	10.7	11.3
d_2 = distance traveled (ft)	477	643	827	1030
Clearance length:				
d_3 = distance traveled (ft)[a]	100	180	250	300
Opposing vehicle:				
d_4 = distance traveled (ft)	318	429	552	687
Total distance, $d_1 + d_2 + d_3 + d_4$ (ft)	1040	1468	1918	2383

[a] For consistent speed relation, observed values are adjusted slightly.

SOURCE: Adapted from *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, Washington, D.C., 2004. Used by permission.

Component of passing maneuver	Metric			
	Speed range (km/h)			
	50–65	66–80	81–95	96–110
	Average passing speed (km/h)			
	56.2	70.0	84.5	99.8
Initial maneuver:				
a = average acceleration[a]	2.25	2.30	2.37	2.41
t_1 = time (sec)[a]	3.6	4.0	4.3	4.5
d_1 = distance traveled	45	66	89	113
Occupation of left lane:				
t_2 = time (sec)[a]	9.3	10.0	10.7	11.3
d_2 = distance traveled	145	195	251	314
Clearance length:				
d_3 = distance traveled[a]	30	55	75	90
Opposing vehicle:				
d_4 = distance traveled	97	130	168	209
Total distance, $d_1 + d_2 + d_3 + d_4$	317	446	583	726

Table 3.7 Suggested Minimum Passing Zone and Passing Sight Distance Requirements for Two-Lane, Two-Way Highways in Mountainous Areas

		Minimum Passing Zone		*Minimum Passing Sight Distance*	
85th-Percentile Speed (mi/h)	*Available Sight Distance (ft)*	*Suggested (ft)*	*MUTCD* (ft)*	*Suggested (ft)*	*MUTCD* (ft)*
	600–800	490		630	
	800–1000	530		690	
30	1000–1200	580	400	750	500
	1200–1400	620		810	
	600–800	520		700	
	800–1000	560		760	
35	1000–1200	610	400	820	550
	1200–1400	650		880	
	600–800	540		770	
	800–1000	590		830	
40	1000–1200	630	400	890	600
	1200–1400	680		950	
	600–800	570		840	
	800–1000	610		900	
45	1000–1200	660	400	960	700
	1200–1400	700		1020	
	600–800	590		910	
	800–1000	630		970	
50	1000–1200	680	400	1030	800
	1200–1400	730		1090	

**Manual on Uniform Traffic Control Devices,* published by FHWA.

SOURCE: Adapted from N.J. Garber and M. Saito, *Centerline Pavement Markings on Two-Lane Mountainous* ... rginia Highway and Transportation Research Council, Char-

Road- Vehicle Characteristics

- **Sight Distance:**

  – Passing Sight Distance (PSD):

Example:

Example 2.3: Passing Sight Distance

What would be the Passing Sight Distance that have to be provided to allow for passing at the crest of a long vertical curve were the design speed V_A=70 kph ? Assume that time for initial maneuver, t_1= 4 sec and the difference in speed between the passing and the passed vehicles, m =10 kph; the acceleration rate, a =1.25 m/s^2; and the time during which the passing vehicle occupies the left lane t_2=10 sec.

Road- Vehicle Characteristics

- **Sight Distance:**

  – Passing Sight Distance **(PSD):**

Example:

Example 2.3: Passing Sight Distance

Solution:

$$PSD = d_1 + d_2 + d_3 + d_4$$

$d_1 = t_1(v\text{-}m + 0.5*a*t_1)$

$= 4[(70-10)*1000/3600 + 0.5*1.25*4) = 76.7$ m

$d_2 = V_A * t_2$

$= 70*(1000/3600)*10 = 194.4$ m

$d_3 = 60$ m (between 30-90 m)

$d_4 = (2/3)*d_2$

$= (2/3)*194.4 = 129.6$m

.7+194.4+60+129.6 = 460.7m

- **Example**: Drivers travel on a freeway at 90 km/hr where an exit ramp are designed for 40 km/hr. What should be the minimum distance of sign with 15 cm letters placed ahead of exit. The following facts are provided: PIEV time = 2.0 sec, deceleration rate a = 3.41 m/sec^2, g = 9.81 m/sec^2, Freeway downgrade = 1%. The drivers can read the sign at 0.75 m per 1 cm height.

- 1. Readability = 15 *0.75 = 11.25 m.
- 2. X = SSD – Readability = SSD – 11.25 m
- 3. SSD = 0.278*U*t +[$(U1)^2$ - $(U2)^{2]}$ /[254((a/g)-G))]
- SSD = 0.278*90*2 + (90*90) – (40*40)/[254((3.41/9.81)-0.01))] = 50.04 + 75.27 = 125.31 m...
- X = 125.31 – 11.25 = 114.06 m.

Introduction to Transportation System Engineering

Thank You Very Much