Human component and vehicle in transportation

Transportation Engineering

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The Traffic System

- 3 Components
  - Roadway/Transport Facilities
  - Vehicle
  - Humans (drivers, passengers, pedestrians)

Road Users

Human as active component of traffic system, Distinguishes it from virtually all other CE fields.

Component Highly variable and unpredictable in capabilities and characteristics.

Physiological – Measurable and Usually Quantifiable

Psychological – Much more difficult to measure and quantify

Driver

Driving task – monitoring and responding to a continuous series of visual and audio cues

Driving task at three levels:

Operational (Control) – vehicle control through second-to-second driver's actions, speed

Tactical (Guidance)– vehicle guidance through maintenance of a safe speed and proper path

Strategic (Navigation) – route planning

Road user types

- Driver
- Passenger
- Cyclist
- Pedestrian

Human Component

- Driver decision process involves
  - Sensing
  - Perceiving
  - Analysing
  - Deciding
  - Responding

Human Component

- Sensing
  - Feeling: forces on the vehicle
  - Seeing: critically important means of acquiring information
    - Ability to see fine details, depth perception, peripheral vision, 'night' vision, glare recovery
  - Hearing: important for drivers, cyclists and pedestrians
  - Smelling: detecting emergencies e.g. overheated engine, burning brakes, fire

Human Component/Perception and Reaction Times

- Perception time is delay between visibility and determining there is a potential hazard
- Perception and Reaction time consists of four stages
  - Perception: Sees or hears situation (sees a stone)
  - Identification: Identify situation (realizes deer is in road)
  - Emotion: Decides on course of action (swerve, stop, change lanes, etc)
  - Reaction (volition) :Acts (time to start events in motion but not actually do action)
    - **Foot begins to hit brake, not actual deceleration**
- Thus, the Total Reaction Time (PIEV) involves analytical and decision-making as well as actual control response (e.g put foot on brake)
- Perception-reaction time (PIEV) often assumed to be 2.5 seconds
  - At 100 kph a vehicle travels about 70 metres in that time

Typical Perception-Reaction time range is:

0.5 to 7 seconds

For design purpose Perception-Reaction Time (PIEV) is assumed to be 2.5 seconds and normally it is taken to represent the behaviour of 85% of drivers

At 100 kph a vehicle travels about 70 metres in that time

It is affected by a number of factors.

What are they?

Perception-Reaction Time Factors

- Environment:
  - Urban vs. Rural
  - Night vs. Day
  - Wet vs. Dry
- Age
- Physical Condition:
  - Fatigue
  - Drugs/Alcohol

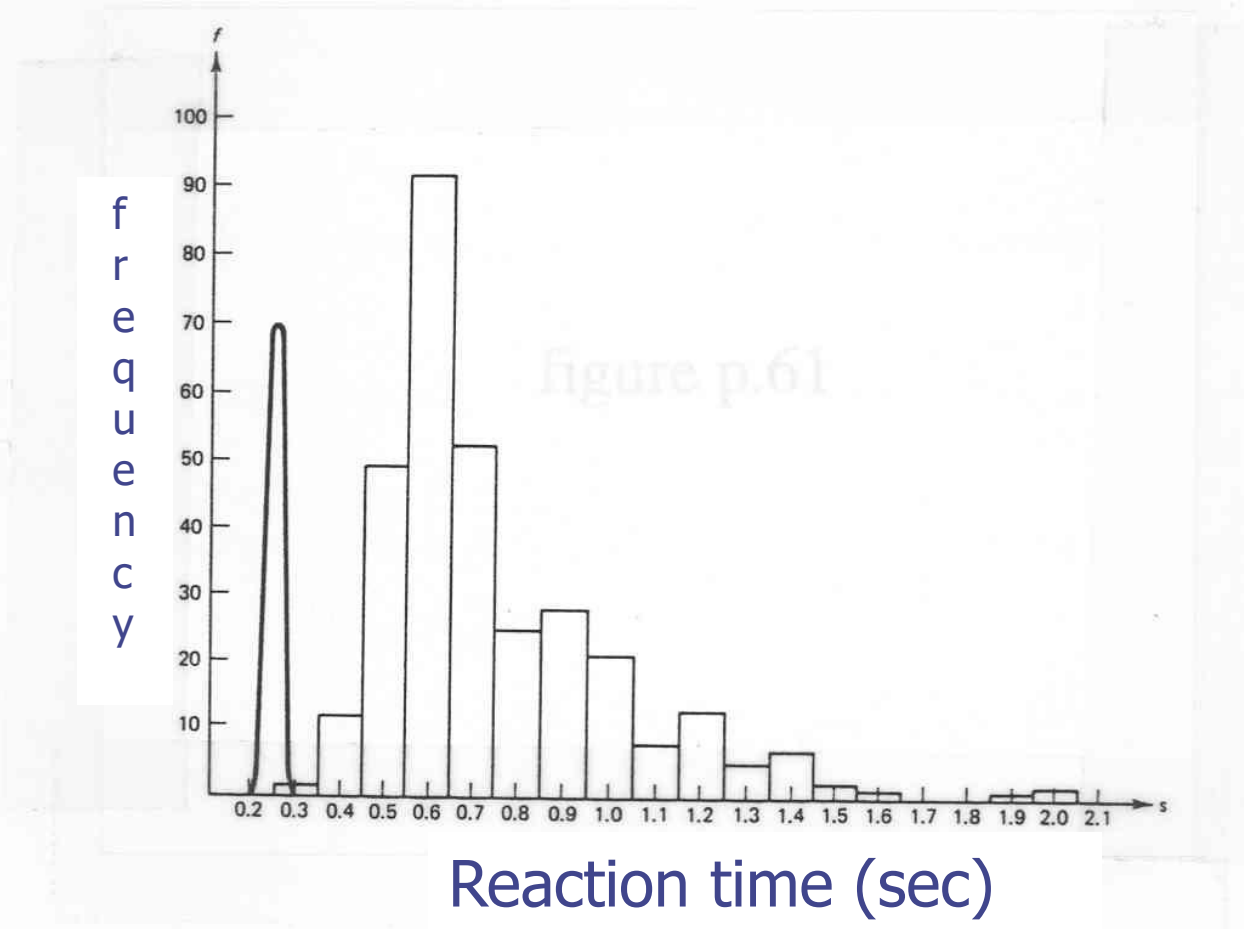
Perception-Reaction Time Factors

- medical condition
- visual acuity
- ability to see (*lighting conditions, presence of fog, snow, etc*)
- complexity of situation (*more complex = more time*)
- complexity of necessary response
- expected versus unexpected situation (*traffic light turning red vs. dog darting into road*)

Other Driver Related Factors

- Age
- Fatigue
- Physical impairments
- Presence of alcohol or other drugs

Variations in Reaction Time



Effect of Task Complexity

$$t_r = a + b \cdot \log_2 N$$

where

t_r = reaction time (s)

a = minimum reaction time under circumstances (s)

b = 0.13, slope

N = no. of alternatives

Example

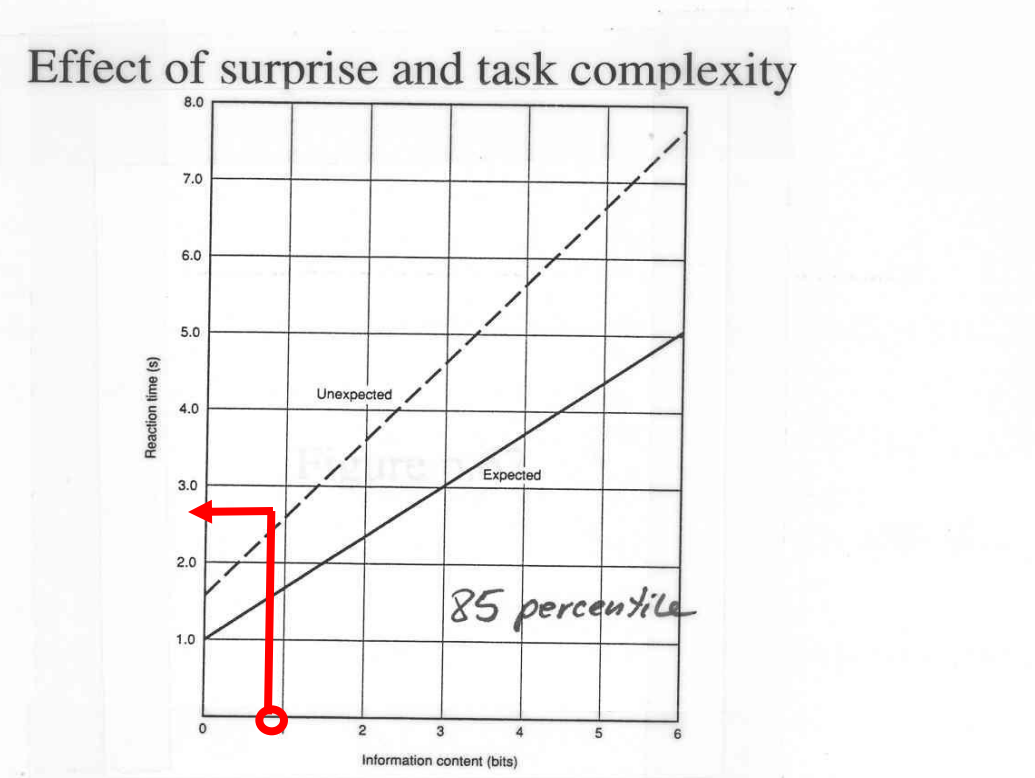
a = 0.15 s and one action is possible, then

t_r = 0.15 +0.13 $\log_2 1$ = 0.15 + 0.13x0 = 0.15 s

If there are two possible actions are to select from, then

t_r = 0.15 +0.13 $\log_2 2$ = 0.15 + 0.13x1 = 0.28 s

Effect of Surprise and Task Complexity



Visual Acuity

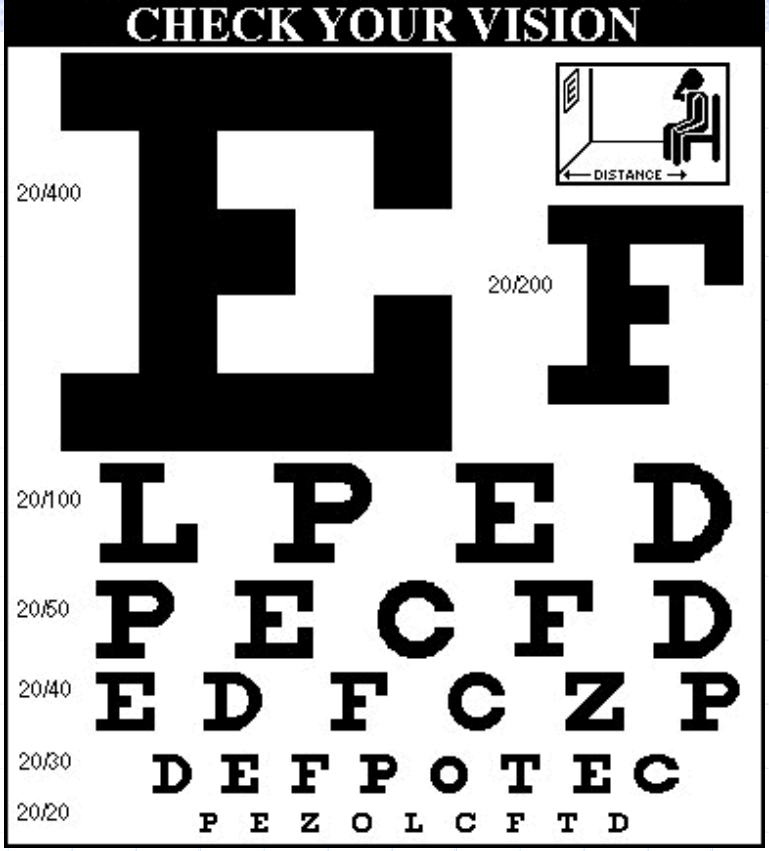
Visual acuity :It refers to the sharpness with which a person can see on object.

One measurement of it is the recognition acuity obtained using Snellen chart.

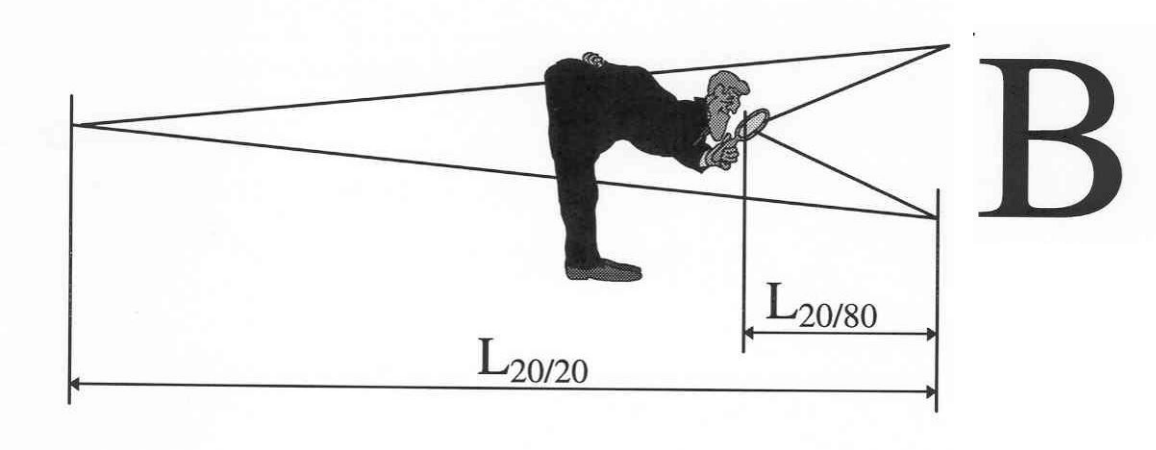
Visual acuity is either static : no motion involved and dynamic : relative motion involved.

Snellen Chart

- Normal Vision
- Recognizing 1/3” letters under well lit conditions from 20”
- A person with 20/40 requires object be twice as large at same distance



- *Visual acuity is 20/20* **if a person can recognize 1/3 in letter at a distance of 20 ft.**
- *Visual acuity is 20/x* **if a person can recognize the letters at the distance** *20/x* **times the distance required by a person with visual acuity 20/20.**



Example

- A driver with 20/20 vision can see sign from 90’. How close must a driver with 20/50 vision be?
- X=90*(Bad/Good)=90*(20/50)/(20/20)
  - X=36’
- If those letters were 2” high, how high should they be for a driver with 20/60 visions (same distance)
  - 6 ’

Static Acuity and Letter Size

Acuity (ft/ft)	20/10	20/20	20/30	20/40	20/50	20/60
Index L/H (ft/in)	114.6	57.3	38.2	28.7	22.9	19.1

Visual acuity is worse when an object is moving

During night conditions, the visual acuity is one column worse

Example

A driver with 20/20 vision can read a sign from a distance of 90 ft. How close must a person with the 20/50 vision be in order to read the same sign?

$$L_{20/50} = L_{20/20} \cdot (20/50)$$

$$L_{20/50} = 90 \cdot (20/50) = 36 \text{ ft}$$

How large should letters be to be recognizable at a distance of 90 ft by a person with the 20/60 vision?

$$(L/H)_{20/60} = 19.1 \text{ ft/in}$$

$$H_{20/60} = 90/19.1 = 4.7 \ \ inch$$

Roadway Sign Readability

- Maximum distance a driver can read a road sign within her/his vision acuity
- = (letter height in inches)*(vision acuity)
- Example
  - letter height of road sign = 4 inches
  - a driver can read a road sign at a distance of 30 ft for each inch of letter height
- Solution
  - readability = (4 in)(30 ft/in) = 120 ft

Roadway Sign Readability

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Sign Legibility

A sign should be legible at a sufficient distance in advance so that the motorist gets time to perceive the sign, its information and perform any required maneuver.

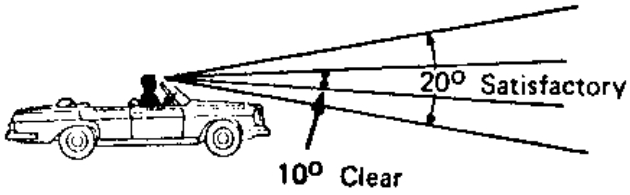
Rule of thumb:

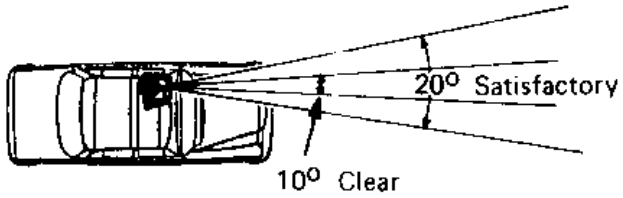
LD = H*50

Where, LD = Legibility distance (ft)

H = Height of letters on the sign (inch)

Human Visual Factors





Visual Acuity Factors:

- 20° cone of satisfactory vision
- 10° cone of clear vision (traffic signs and signals should be within this cone)
- 3° cone of optimum vision
- 160 ° cone of vision defines the peripheral vision (Driver can see object but with no clear details)

Aging's impact of vision

- Older persons experience low light level
  - Rules of thumb – after 50 the light you can see halves with each 10 years
- Glare – overloading eye with light
  - Older drivers can take twice as long to recover from glare
- Poor discrimination of color
- Poor contrast sensitivity

Pedestrian Characteristics

Walk Speed:

4.0 fps Safe or 15th

5.0 fps Median

6.0 fps 85th

Design Vehicle

- Design Vehicle – largest (slowest, loudest?) vehicle likely to use a facility with considerable frequency
- Three Characteristics
  - Physical
  - Operating
  - Environmental

Physical Characteristics

- Type Passenger Car
  - Motorcycle
  - Truck
- Size (Several examples)
  - Length
  - Height
  - Weight
  - Width
  - Minimum and Maximum Turning Radii

Operating Characteristics

- Acceleration
- Deceleration and braking
- Power/weight ratios
- Turning radius
- Headlights

Environmental Characteristics

- Noise
- Exhaust
- Fuel Efficiency

Vehicle Characteristics

- Static: those characteristics that DO NOT depend on the interaction with the transportation facility
- Dynamic: those characteristics that DO depend on the interaction with the transportation facility

Vehicle Performance

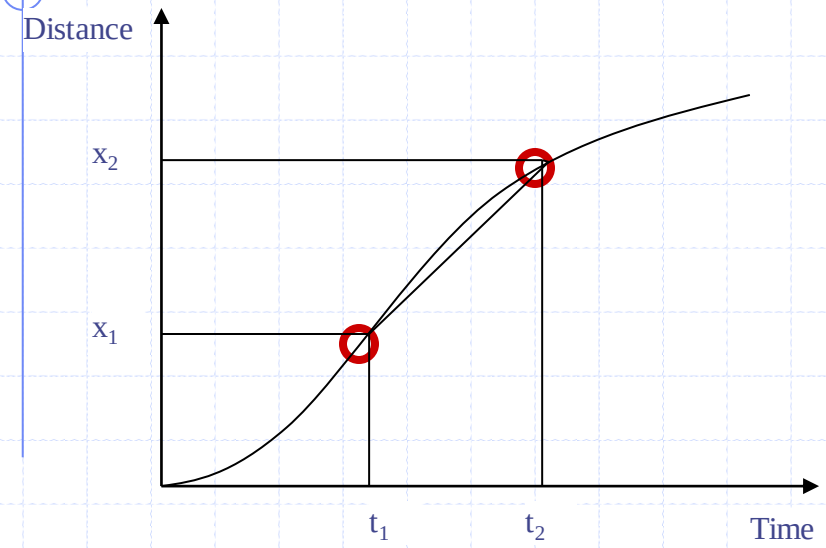
Impact of vehicle performance on

- Road Design
- Traffic operations
- Truck Performance on Grades

Motion of vehicles

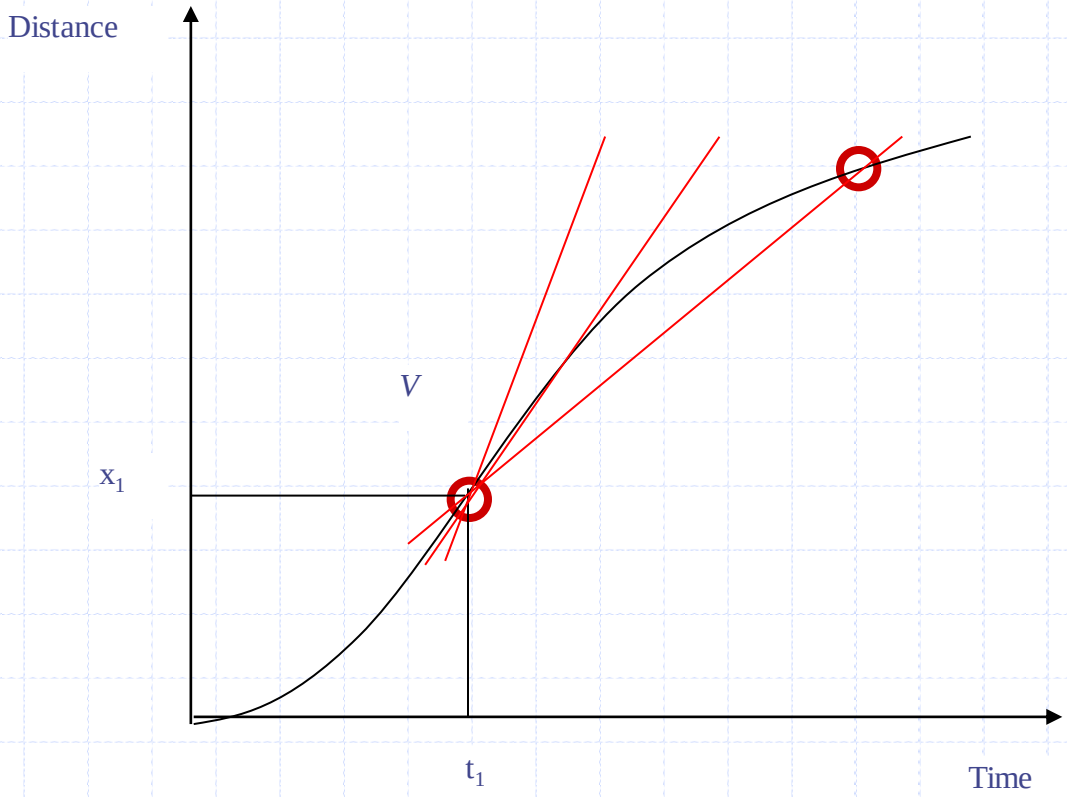
1. Rectilinear motion
   - Constant acceleration rate
   - Acceleration as function of speed
2. Motion on circular curves

Travel Speed



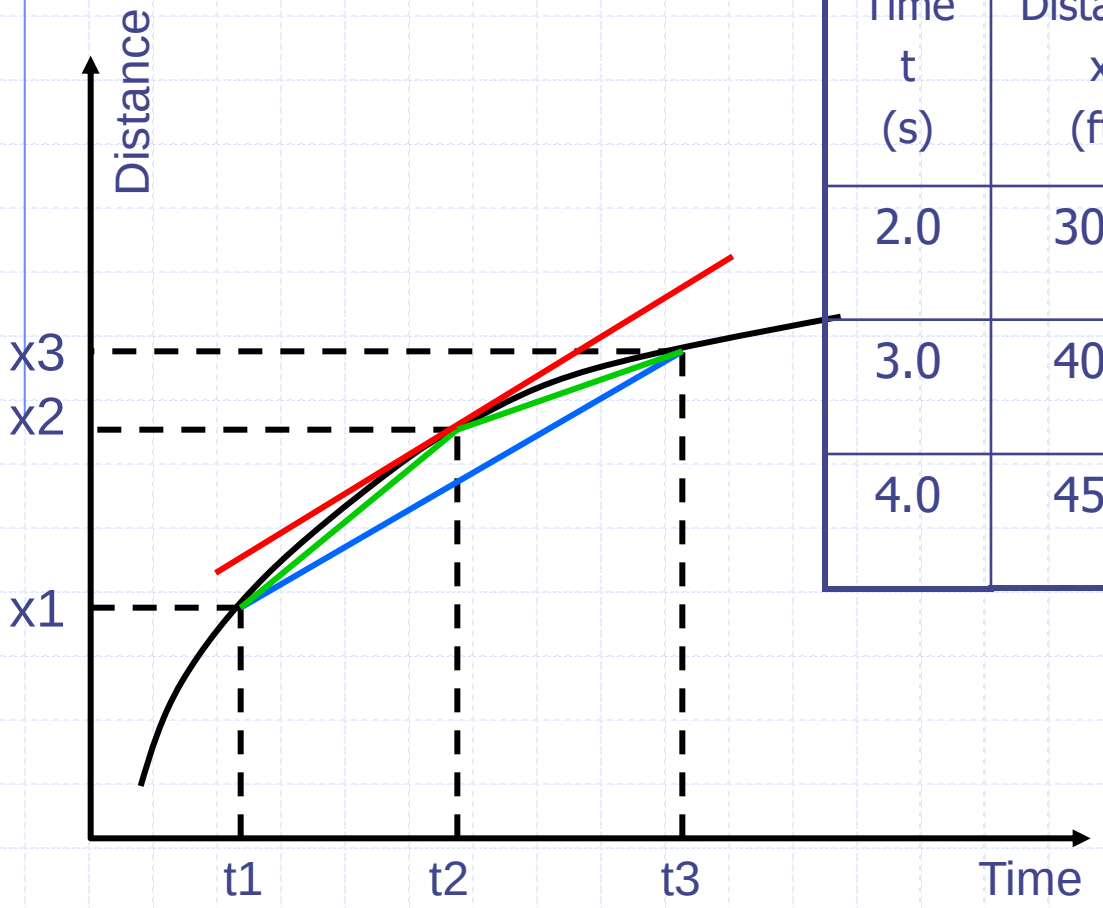
$$v = \frac{x_2 - x_1}{t_2 - t_1}$$

Spot Speed



$$v = \frac{dx}{dt}$$

Spot Speed Measurements

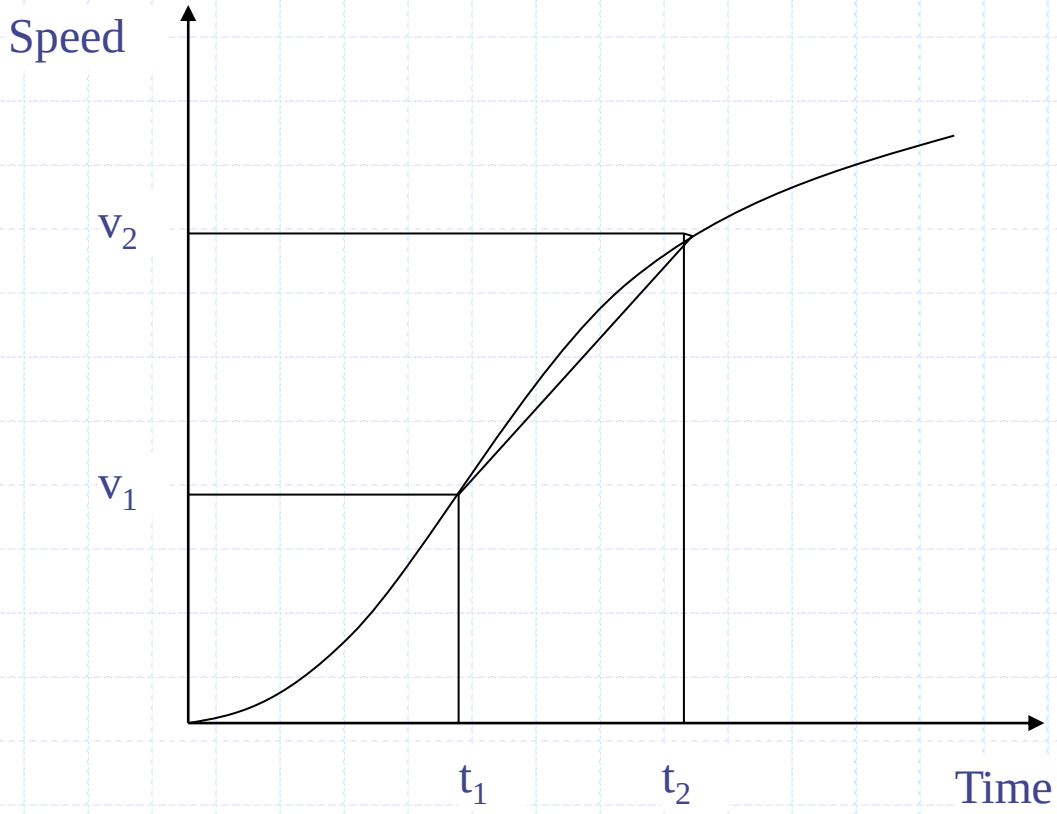


Time t (s)	Distance x (ft)	Speed 1 v (ft/s)	Speed 2 v (ft/s)
2.0	30.0	---	---
3.0	40.0	(40-30)/(3-2) =10.0	(45-30)/(4-2) = 7.5
4.0	45.0	(45-40)/(3-2) =5.0	---

Spot Speed Measurements

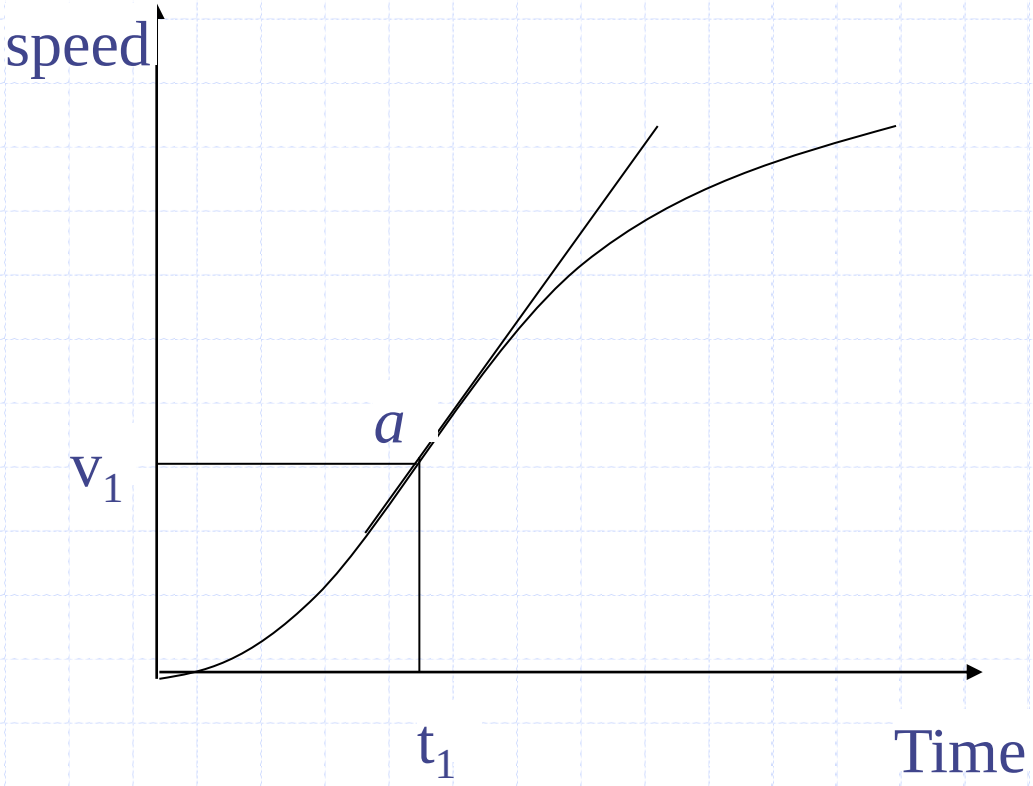
Time (s)	Distance (ft)	Speed (ft)
0.0	0.0	-
0.1	2.13	21.5
0.2	4.30	21.9
0.3	6.51	22.4
0.4	8.78	22.4
0.5	10.99	21.3
0.6	13.04	-

Average Acceleration Rate



$$a = \frac{v_2 - v_1}{t_2 - t_1}$$

Spot Acceleration Rate



$$a = \frac{dv}{dt}$$

Measuring Acceleration Rates

Time (s)	Distance (ft)	Speed (ft/s)	Acceleration (ft/s^2)
0.0	0.0	-	-
0.1	2.13	21.5	-
0.2	4.30	21.9	4.5
0.3	6.51	22.4	2.5
0.4	8.78	22.4	-5.5
0.5	10.99	21.3	-
0.6	13.04	-	-

Constant Acceleration Motion

$$\frac{dv}{dt} = a = const$$

$$\int_{v_0}^{v} dv = \int_{0}^{t} a\,dt$$

$$\boxed{v = at + v_0}$$

$$\frac{dv}{dx} v = a$$

$$\int_{v_0}^{v} v\,dv = \int_{0}^{x} a\,dx$$

$$\boxed{x = \frac{v^2 - v_0^2}{2a}}$$

$$dx = v\,dt = (at + v_0)\,dt$$

$$\int_{0}^{x} dx = \int_{0}^{t} (at + v_0)\,dt$$

$$\boxed{x = \frac{1}{2} a t^2 + v_0 t}$$

Remark: The equation used for design is $\boxed{x = \frac{v_0^2 - v^2}{2a}}$, where the deceleration rate has a positive value.

Exercise

- From the following data, calculate the acceleration rate at the distance of 2 feet from the reference point.

$a = 5.91 ft/s^{2???}$

Distance (ft)	Speed (ft/s)
0	19.4
1	19.6
2	20.0
3	20.8
4	21.3

Power Requirements

- Engine power required to overcome air grade, curve, and friction resistance to keep vehicle in motion
- Power: rate at which work is done
- 1 HP = 550 lb-ft/sec

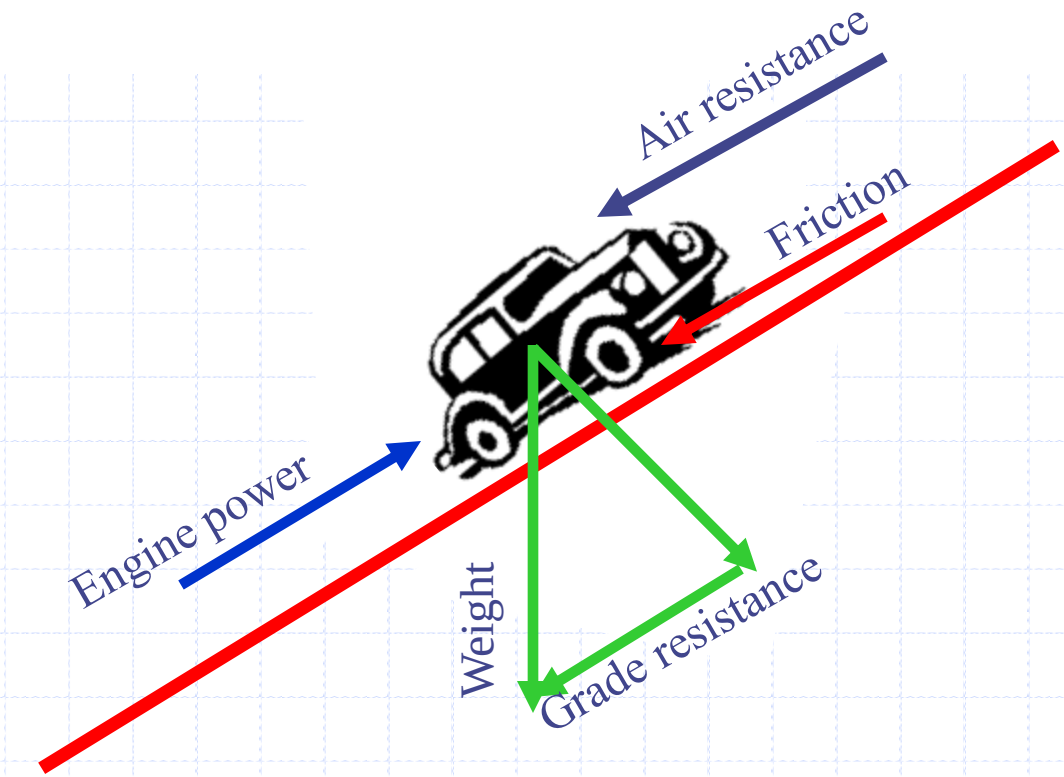
$$P = \frac{1.47Ru}{550}$$

where;

P = horsepower

R = sum of resistance

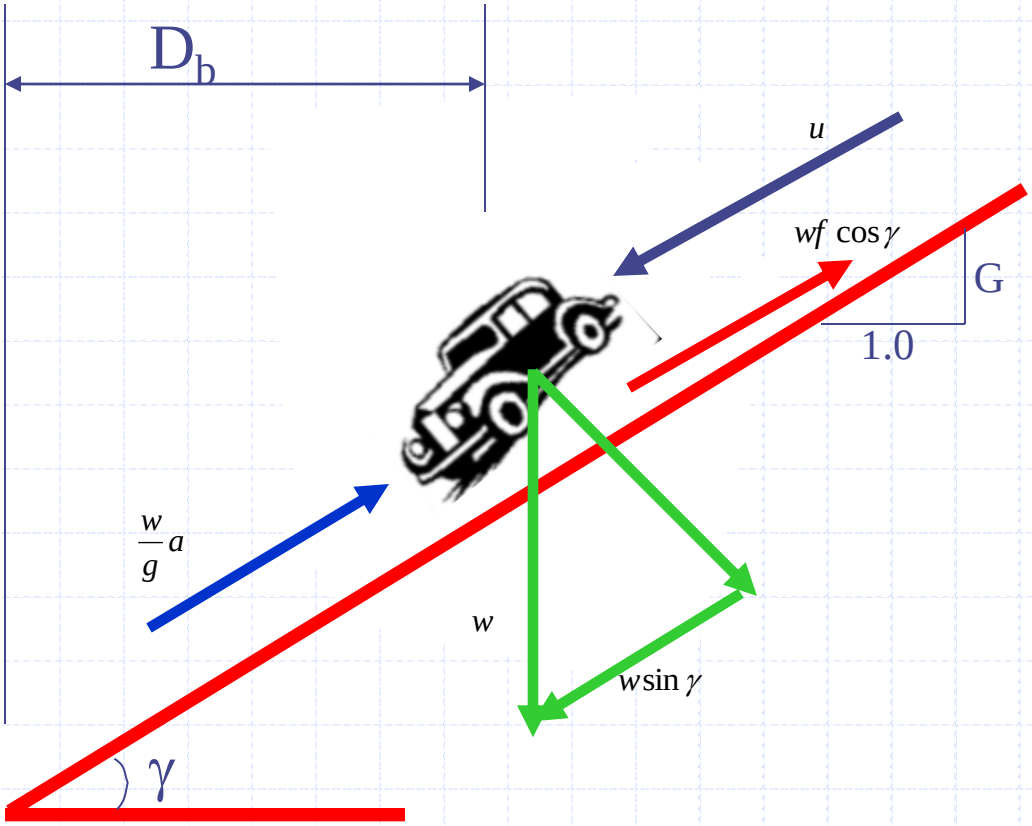
u = speed (mi/hr)



Hill Climbing Ability

- Force acting on a vehicle:
  - Engine Power
  - Air Resistance
  - Grade Resistance
  - Rolling Resistance
  - Friction
  - Weight

Braking Distance

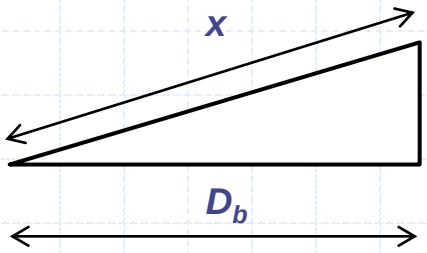


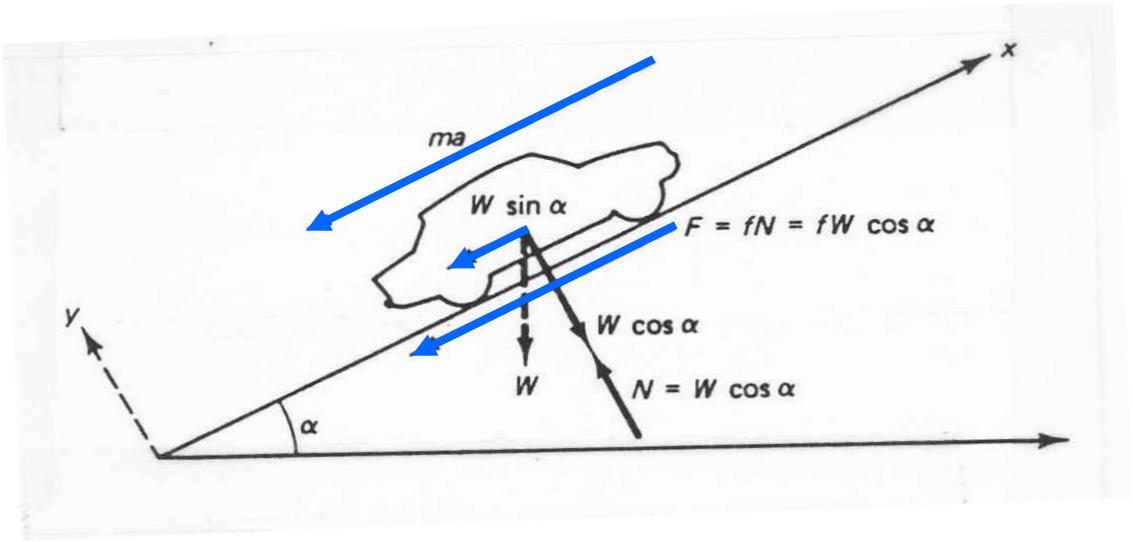
Distance to stop vehicle

Braking on Grades

$$\left(\frac{W}{g}\right)a = Wf\cos\alpha \pm W\sin\alpha$$

$$x = \frac{v_0^2 - v^2}{2a}$$





$$D_b = x\cos\alpha = \frac{v_0^2 - v^2}{2a}\cos\alpha \qquad a = (v_0^2 - v^2)\frac{\cos\alpha}{2D_b}$$

$$\left(\frac{1}{g}\right)(v_0^2 - v^2)\frac{\cos\alpha}{2D_b} = f\cos\alpha \pm \sin\alpha \Big/ \cos\alpha$$

$$\boxed{D_b = \frac{v_0^2 - v^2}{2g(f \pm G)}}$$

$$\left(\frac{1}{g}\right)(v_0^2 - v^2)\frac{1}{2D_b} = f \pm \frac{\sin\alpha}{\cos\alpha} \qquad \frac{\sin\alpha}{\cos\alpha} = \tan\alpha = G$$

Braking distance

- **Braking Distance (Db)**
- Db = distance from brakes enact to final speed
- Db = f(velocity, grade, friction)
- $Db = (V_0^2 - V^2)/[30(f +/- G)]$
- or
- $Db = (V_0^2 - V^2)/[254(f +/- G)]$ metric
  - Db = braking distance (feet or meters)
  - V_0 = initial velocity (mph or kph)
  - V = final velocity (mph or kph)
  - f = coefficient of friction
  - G = Grade (decimal)
    30 or 254 = conversion coefficient

Braking Distance

- AASHTO represents friction as a/g which is a function of the roadway, tires, etc
- Can use when deceleration is known (usually not) or use previous equation with friction

$$Db = \frac{u^2}{30(\{a/g\} \pm G)}$$

D_b = braking distance
u = initial velocity when brakes are applied
a = vehicle acceleration
g = acceleration of gravity (32.2 ft/sec^2)
G = grade (decimal)

Vehicle Braking Distance

Factors

- Braking System
- Tire Condition
- Roadway Surface
- Initial Speed
- Grade

Braking Distance Equation

$$d_b = (V^2 - U^2) / 30(f + g)$$

Coefficient of friction

Pavement condition	Maximum	Slide
Good, dry	1.00	0.80
Good, wet	0.90	0.60
Poor, dry	0.80	0.55
Poor, wet	0.60	0.30
Packed snow and Ice	0.25	0.10

Skid mark

- A skid mark is a tire mark on the road surface produced by a tire that is locked, that is not rotating.
- A skid mark typically appears very light at the beginning of the skid getting darker as the skid progresses and comes to an abrupt end if the vehicle stops at the end of the skid.
- A skid mark is left when the driver applies the brakes hard, locking the wheels, but the car continues to slide along the road. Steering is not possible with the front wheels locked. Skid marks are generally straight but may have some curvature due to the slope of the road.

Skid mark measurements





Sight distance

Distance a driver can see ahead at any specific time

Must allow sufficient distance for a driver to perceive/react and stop, swerve etc when necessary

Stopping Sight Distance

Distance to stop vehicle, includes P/R and braking distance

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

where:

D_b = braking distance

u = initial velocity when brakes are applied

f = coefficient of friction

G = grade (decimal)

t = time to perceive/react

a = vehicle acceleration

g = acceleration due to gravity (32.2 ft/sec^2)

Stopping Sight Distance

With assumed acceleration, using friction

$$S = 1.47ut + \frac{u^2}{30(f \pm G)}$$

where:

D_b = braking distance

u = initial velocity when brakes are applied

f = coefficient of friction

G = grade (decimal)

t = time to perceive/react

SSD Example

- A vehicle is traveling at uniform velocity, at t_0 the driver realizes a vehicle is stopped in the road ahead and the driver brakes
- Grade = + 1%
- $t_{P/R}$ = 0.8 sec
- The stopped vehicle is just struck, assume $v_f = 0$
- The braking vehicle leaves skid marks that are 405 feet long
- Assume normal deceleration (11.2 ft/sec^2)
- Should the police office at the scene cite the driver for traveling over the 55 mph posted speed limit?

SSD Example

$$SSD = 1.47ut + \frac{u^2}{30(\{a/g\} \pm G)}$$

Stopping distance = 405 feet

$$405 \text{ feet} = 1.47u(0.8 \text{ sec}) + \frac{u^2}{30(\{11.2/32.2\} + 0.01)}$$

$$405 \text{ feet} = 1.17u + \frac{u^2}{30(0.358)}$$

$$405 \text{ feet} = 1.17u + \frac{u^2}{10.73}$$

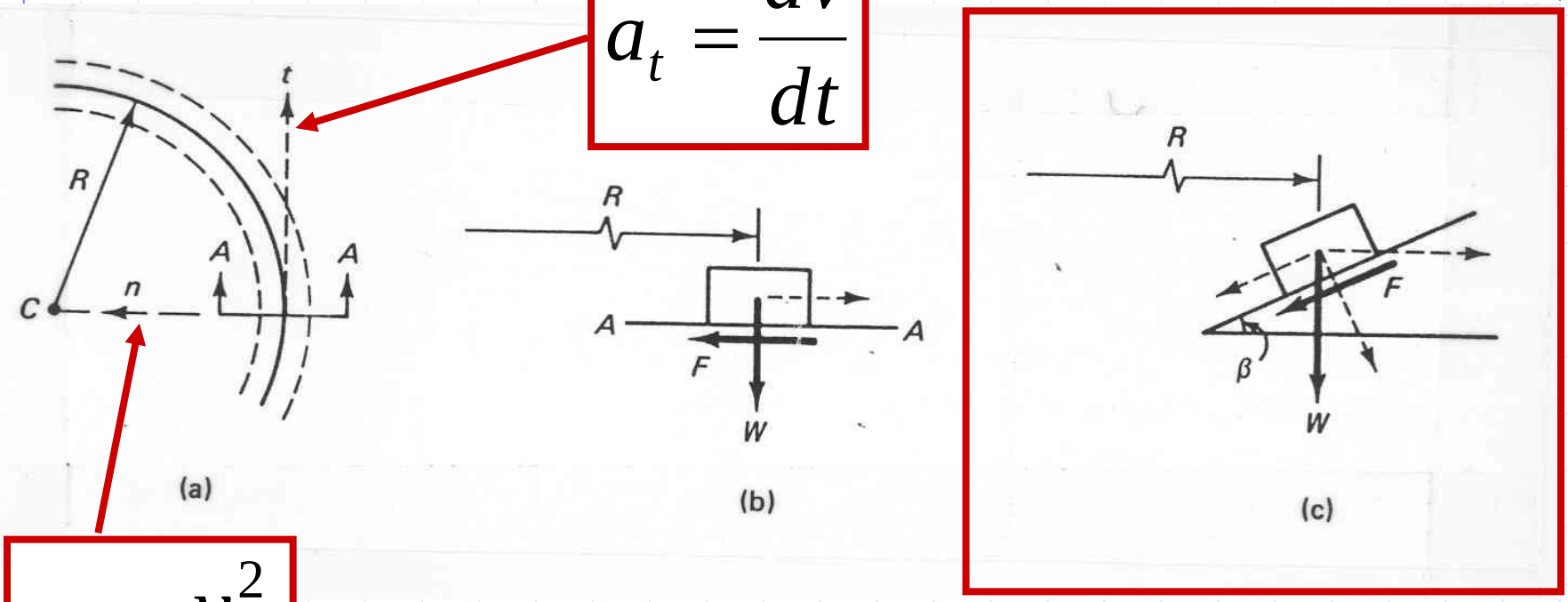
Solving for u, u = 59.9 mph

Decision Sight Distance

When situation is unexpected or driver makes unusual maneuvers or under difficult to perceive situations
Requires higher P/R time
Depends on type of maneuver made and roadway setting (urban vs. rural)
Use table 3.5 from Text, page 75

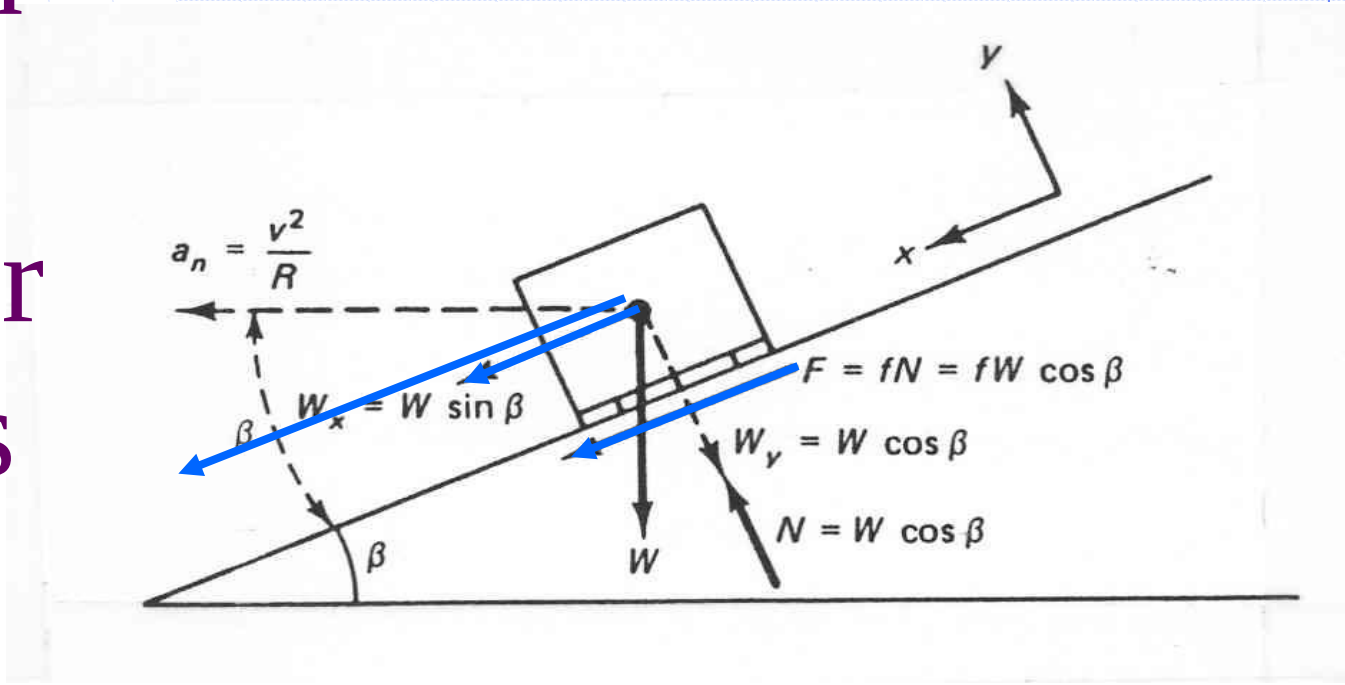
Motion on Circular Curves

$$a_t = \frac{dv}{dt}$$



$$a_n = \frac{v^2}{R}$$

Motion on Circular Curves



$$W \sin\beta + f_s W \cos\beta = m a_n \cos\beta$$

$$W \sin\beta + f_s W \cos\beta = \frac{W}{g}\left(\frac{v^2}{R}\right)\cos\beta \;\Big/ W\cos\beta$$

$$\frac{\sin\beta}{\cos\beta} = \tan\beta = e$$

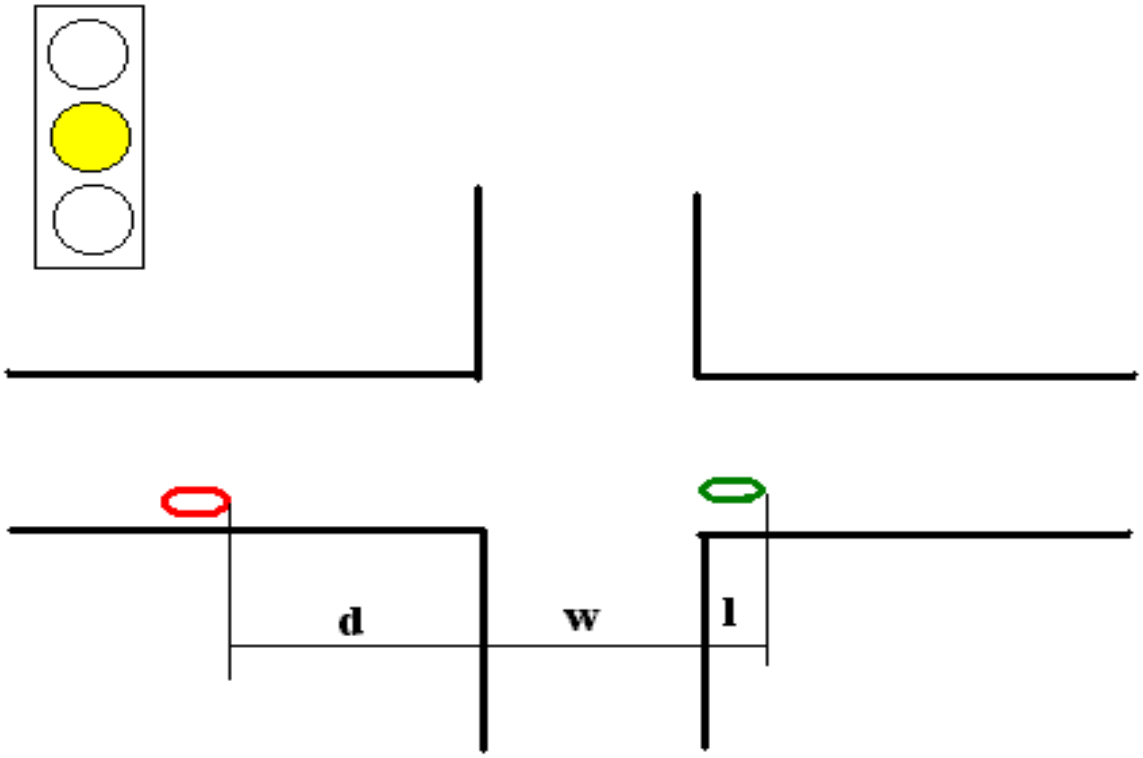
$$e + f_s = \frac{v^2}{gR}$$

Minimum Radius of a Circular Curve

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

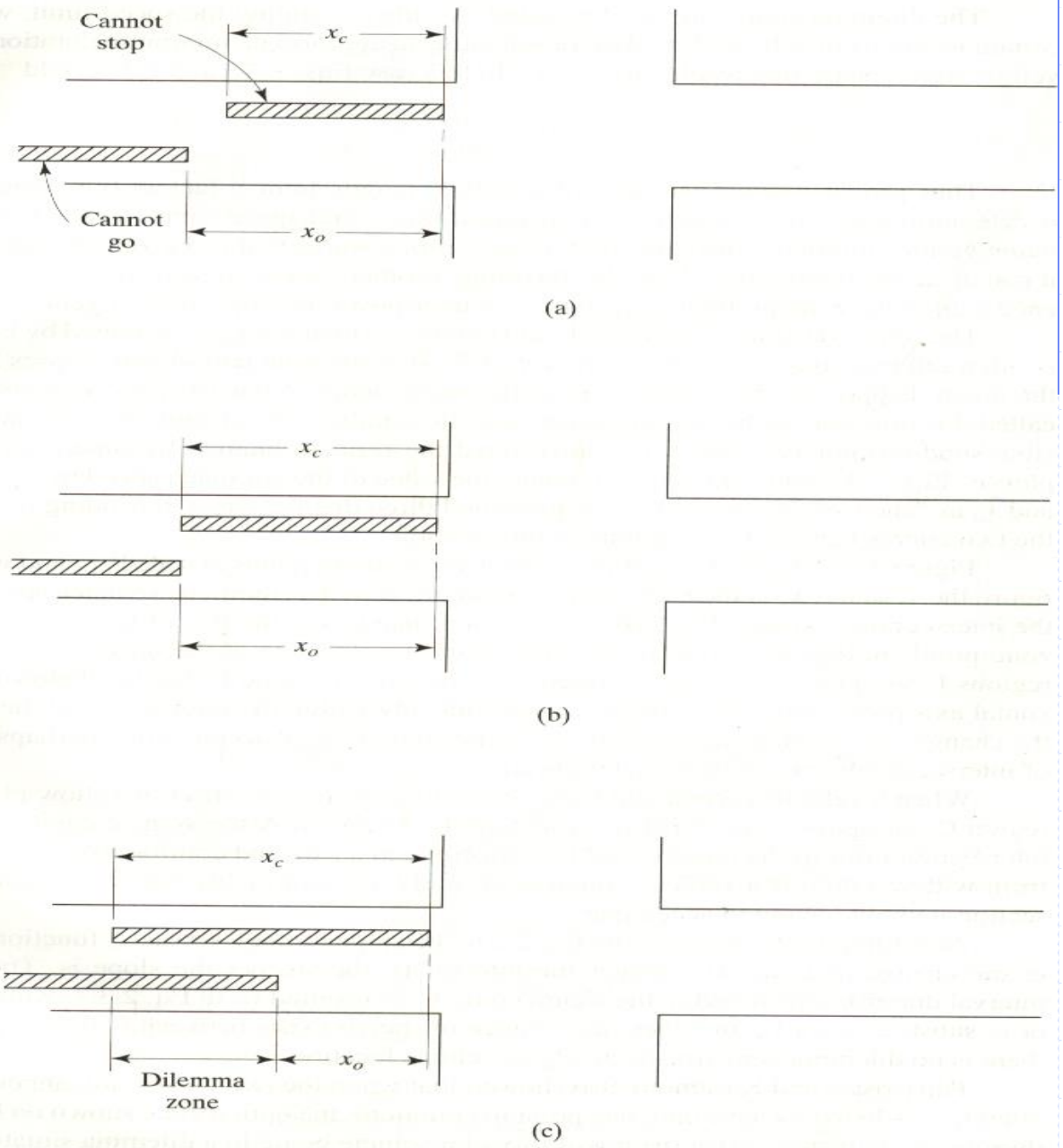
- where u = vehicle velocity (mph)
- e = tan α (rate of superelevation)
- f_s = coefficient of side friction (depends on design speed)
- Example
  - design speed = 65 mph
  - rate of superelevation = 0.05
  - coefficient of side friction = 0.11
- Solution
  - minimum radius
  - $R = (65)^2/[15(0.05+0.11)] = 1760$ ft

Change Interval at Traffic Signals



clearence Interval at Signalized Intersections

Dilemma zone



Calculation

- Vehicle Able to Stop = d = 1.47(V)(t)+(V^2)/30(f)
- Vehicle Travel Through = d + w + l
- Change Interval (Amber) = $\frac{d + w + l}{1.47V}$

Change Interval = $\frac{1.47Vt + \frac{V^2}{30f} + w + l}{1.47V}$

= $t + \frac{V}{1.47(30)(f)} + \frac{w+l}{1.47V}$

t = 1.0 s

Roadway Component

- Roads serve four functions since they cater for
  - moving vehicles
  - parked vehicles
  - pedestrians and non-motorised vehicles
  - allow development and access to abutting property
- Functions are inherently conflicting and inconsistent
  - 'movement' versus 'access'

Roadway Component

- Important design considerations:
  - Capacity
  - Safety
- Design includes:
  - Horizontal alignment
  - Vertical alignment
  - Linemarking and signage
  - Pavement design