

Safety on the Highway

Chapter objectives covered in CE361: By the end of this chapter the student will be able to:

1. Know how a highway safety improvement program is conducted
2. Use human factors in the design and analysis of highways for safety
3. Evaluate and design roadway sections for safe stopping sight distance
4. Apply prescribed standards in the use of roadway signs and markings

6.1 Highway Safety – Data and Analysis

By the end of this section, the student will be able to...

● Objectives of 6.1

- Describe the scope of the transportation safety problem.
- Outline a framework for safety analysis and improvement.
- Explain the nature of crash data: potentials and pitfalls.
- Compute crash rates.

Note: section 6.1.4 is not covered in this class.

6.1.1 History and Perspective

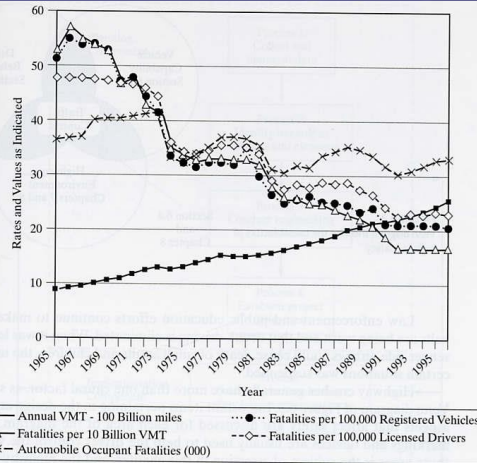


FIGURE 6.2
Highway fatality data since the formation of the NHTSA. Sources: Statistical Abstract of U.S., 2000 and National Personal Transportation Survey of 1990.



■ Accident rates are decreasing but the number of deaths has remained near 40,000/year (In China, about 110,000/year die!!)



NHTSA
www.nhtsa.gov

National Highway Traffic Safety Administration

Our Mission: Save lives, prevent injuries, reduce vehicle-related crashes

NCSA DATA RESOURCE WEBSITE

 **FATALITY ANALYSIS REPORTING SYSTEM
ENCYCLOPEDIA**

Pubs/Data Requests				FARS Data Tables				Query FARS Data				State Traffic Safety Info				Help					
				Summary				Trends				Crashes				Vehicles		People		States	
				General																	

Did You Know?

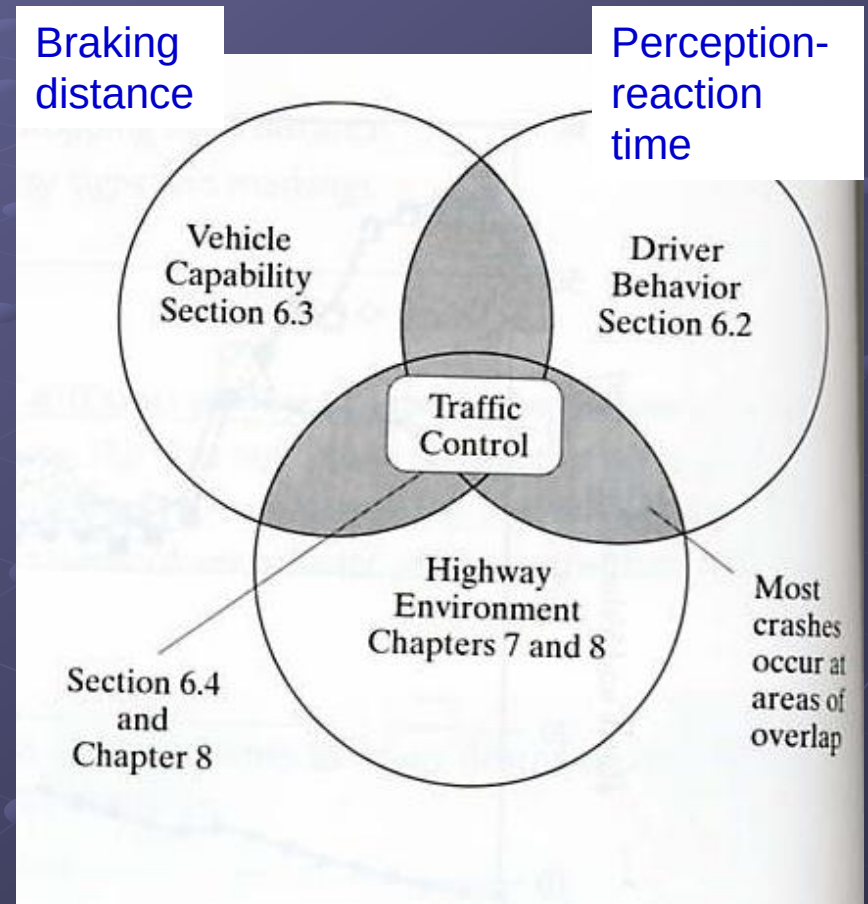
[View Archive](#)

- Fatal crashes decreased by 3.6 percent from 2006 to 2007, and the fatality rate dropped to 1.36 fatalities per 100 million vehicle miles of travel in 2007.
[Trends 2007]
- In 2007, all 50 States, the District of Columbia, and Puerto Rico had safety belt use laws. All 50 States, the District of Columbia, and Puerto Rico also had laws requiring children of certain ages to be restrained in child safety seats.
[States 2007]
- Thirty-two

National Statistics																		
File Versions	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994		
Motor Vehicle Traffic Crashes																		
Fatal Crashes	30,797	34,172	37,435	38,648	39,252	38,444	38,477	38,491	37,862	37,526	37,140	37,107	37,324	37,494	37,241	36,254		
Traffic Crash Fatalities																		
Vehicle Occupants																		
Drivers	17,640	19,279	21,717	22,831	23,237	23,158	23,352	23,625	22,914	22,914	22,971	22,654	22,730	22,572	22,370	21,596		
Passengers	6,770	7,441	8,716	9,187	9,750	10,042	10,171	10,370	10,227	10,451	10,325	10,327	10,765	10,860	10,576	10,294		
Unknown	64	71	94	101	83	76	104	110	102	86	96	107	114	102	118	108		
Sub Total1	24,474	26,791	30,527	32,119	33,070	33,276	33,627	34,105	33,243	33,451	33,392	33,088	33,609	33,534	33,064	31,998		
Motorcyclists	4,462	5,312	5,174	4,837	4,576	4,028	3,714	3,270	3,197	2,897	2,483	2,294	2,116	2,161	2,227	2,320		
Nonmotorist																		
Pedestrians	4,092	4,414	4,699	4,795	4,892	4,675	4,774	4,851	4,901	4,763	4,939	5,228	5,321	5,449	5,584	5,489		
Pedalcyclists	630	718	701	772	786	727	629	665	732	693	754	760	814	765	833	802		
Other/ Unknown	150	188	158	185	186	130	140	114	123	141	149	131	153	154	109	107		
Sub Total2	4,872	5,320	5,558	5,752	5,864	5,532	5,543	5,630	5,756	5,597	5,842	6,119	6,288	6,368	6,526	6,398		
Total**	33,808	37,423	41,259	42,708	43,510	42,836	42,884	43,005	42,196	41,945	41,717	41,501	42,013	42,065	41,817	40,716		
Other National Statistics																		
Vehicle Miles Traveled (Billions)	2,979	2,974	3,032	3,014	2,989	2,965	2,890	2,856	2,797	2,747	2,691	2,632	2,562	2,486	2,423	2,358		
Resident Population (Thousands)	307,007	304,375	301,580	298,593	295,7													

6.1.2 Factors that contribute to highway safety

- Vehicle safety regulatory standards for vehicle parts
- The design of highways
- The social pressure to reduce drunk driving
- Enhanced driver training
- The installation of seat belts and airbags
- Improving a national speed limit



6.1.3 Highway safety improvement programs

HSIP (Highway Safety Improvement Program): a federal government effort to reduce crash casualties, consisting of three components.

Crash inventory is one of the most important things that you must have for implementing effective safety improvement programs.

Without it, accident rates cannot be determined.

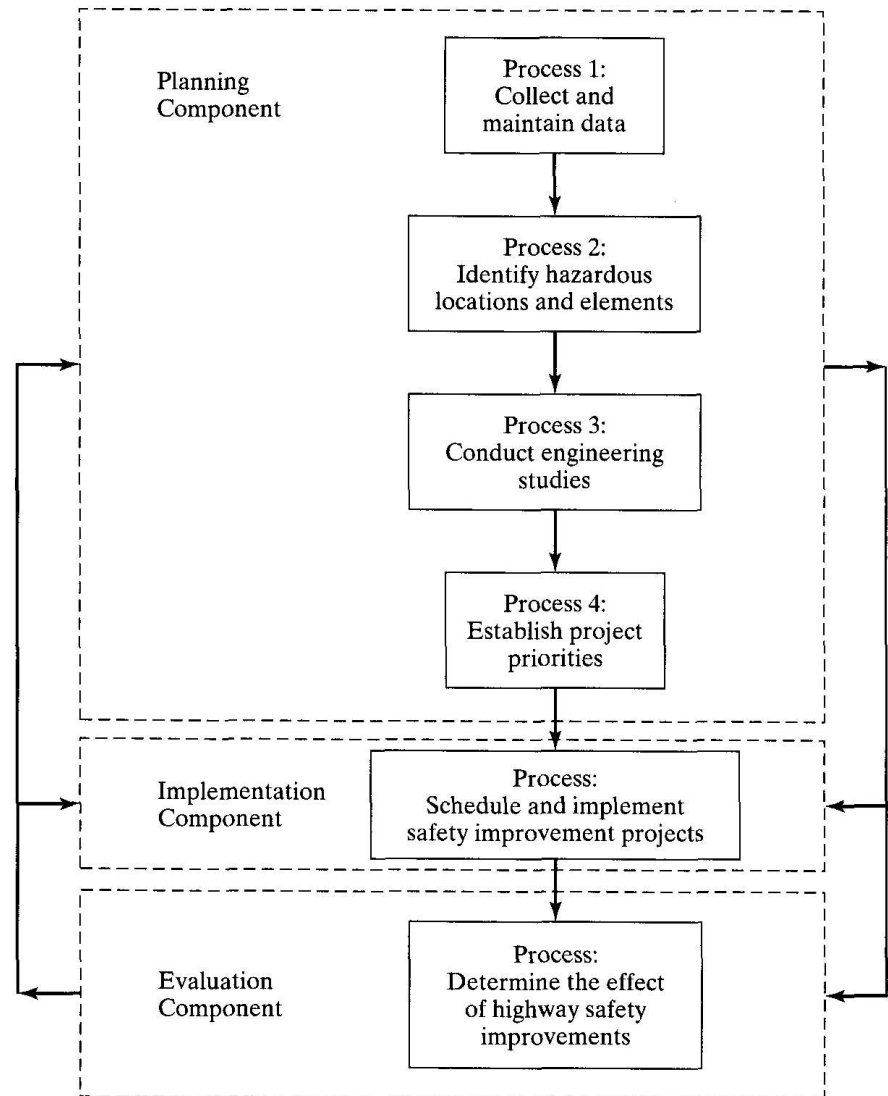
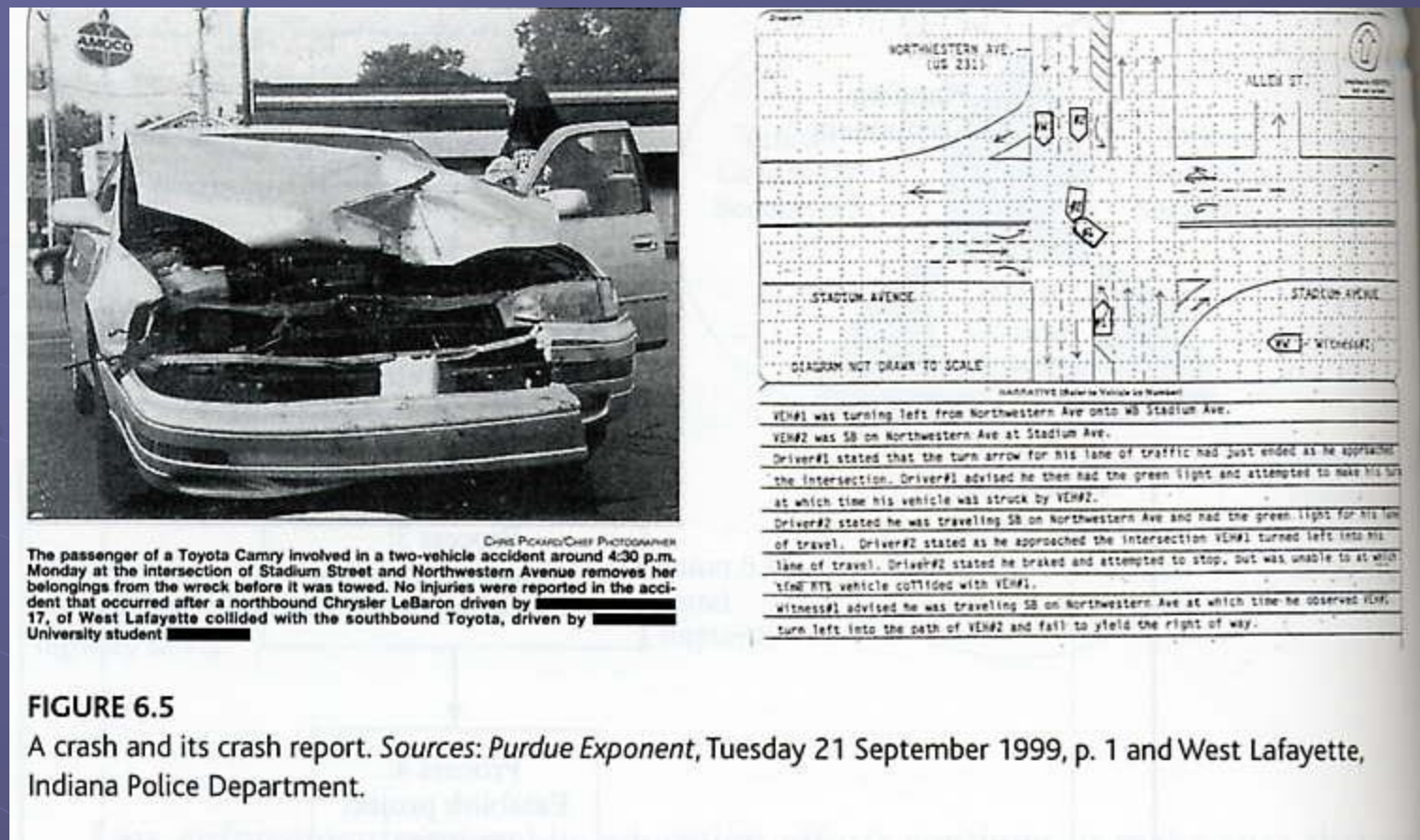


FIGURE 6.4

Highway Safety Improvement Program at the process level. Source: FHWA, 1981.

Planning component, Process 1: Collect and maintain data



Local data: State data: Fatality Analysis Reporting System (FARS)

police reports

UDOT's crash data

Chapter 6

Planning component, Process 2: Identify hazardous locations and elements

Rate per million of entering vehicles (for intersections):

$$\text{RMEV} = \frac{\text{crashes/year}}{\text{approach ADT} * \text{days/year}} * 10^6 \quad (6.1)$$

Rate per million vehicle miles (for highway segments):

$$\text{RMVM} = \frac{\text{crashes/year}}{\text{ADT} * \text{days/year} * \text{miles in section}} * 10^6 \quad (6.2)$$

Killed									
Year	Killed	Resident Population (Thousands)	Fatality Rate per 100,000 Population	Licensed Drivers (Thousands)	Fatality Rate per 100,000 Licensed Drivers	Registered Motor Vehicles	Fatality Rate per 100,000 Registered Vehicles	Vehicle Miles Traveled (Billions)	Fatality Rate per 100 Million VMT
1989	45,582	246,819	18.47	165,554	27.53	181,165	25.16	2,096	2.2
1998	41,501	270,248	15.36	184,980	22.44	207,588	19.99	2,625	1.6

Recent stats

2009

1994

Total**	33,808	37,423	41,259	42,708	43,510	42,836	42,884	43,005	42,196	41,945	41,717	41,501	42,013	42,065	41,817	40,716
Other National Statistics																
Vehicle Miles Traveled (Billions)	2,979	2,974	3,032	3,014	2,989	2,965	2,890	2,856	2,797	2,747	2,691	2,632	2,562	2,486	2,423	2,358
Resident Population (Thousands)	307,007	304,375	301,580	298,593	295,753	293,046	290,326	287,804	285,082	282,172	272,691	270,248	267,784	265,229	262,803	260,327
Registered Vehicles (Thousands)	-	257,494	255,748	251,415	245,628	237,949	230,633	225,685	221,230	217,028	212,685	208,076	203,568	201,631	197,065	192,497
Licensed Drivers (Thousands)	-	208,321	205,742	202,810	200,549	198,889	196,166	194,602	191,276	190,625	187,170	184,861	182,709	179,539	176,628	175,403
National Rates: Fatalities																
Fatalities per 100 Million Vehicle Miles Traveled	1.13	1.26	1.36	1.42	1.46	1.44	1.48	1.51	1.51	1.53	1.55	1.58	1.64	1.69	1.73	1.73
Fatalities per 100,000 Population	11.01	12.30	13.68	14.30	14.71	14.62	14.77	14.94	14.80	14.87	15.30	15.36	15.69	15.86	15.91	15.64
Fatalities per 100,000 Registered Vehicles	-	14.53	16.13	16.99	17.71	18.00	18.59	19.06	19.07	19.33	19.61	19.95	20.64	20.86	21.22	21.15
Fatalities per 100,000 Licensed Drivers	-	17.96	20.05	21.06	21.70	21.54	21.86	22.10	22.06	22.00	22.29	22.45	22.99	23.43	23.68	23.21

** Total fatalities for 1996 include 2 fatalities of unknown person type.

Example 6.1

Example 6.1

Several intersections in Mythaca had an apparent increase in collisions last year. One such intersection—Fisk at Kissimmee—may need some special attention. It had 13 crashes. The four legs of that intersection had two-way ADT values of 9671, 2893, 9506, and 2611 vehicles per day last year. Calculate the intersection's crash rate, so that it may be compared with the rate for other similar intersections.

Solution to Example 6.1 Equation 6.1 uses *approach* ADT, not two-way ADT. That part of a road's ADT that departs from the intersection must be excluded.

A reasonable way to estimate approach ADT is to take half of the two-way ADT. Therefore, the intersection crash rate at Fisk and Kissimmee last year was

$$\text{RMEV} = \frac{13}{0.5 * (9671 + 2893 + 9506 + 2611) * 365} * 10^6 = \frac{13}{0.5 * 24,681 * 365} * 10^6 = 2.886$$

Example 6.2

Example 6.2

A new state highway safety program offers funds to improve local roads with RMVM values greater than 1.00. A 6.1-mile section of Tyler Road in Mythaca County had six crashes last year. The two-way ADT was 755 vehicles per day. Does Tyler Road qualify for the state program?

Solution to Example 6.2 Unlike the intersection crash rate, the roadway section crash rate uses the two-way ADT.

$$\text{RMVM} = \frac{6 \text{ crashes}}{755 \text{ vpd} * 365 \text{ days} * 6.1 \text{ miles}} * 10^6 = 3.57$$

Tyler Road had an average of only one crash per mile last year, but the corresponding crash rate was high enough to qualify for state funds.

Determining high-crash locations (p.312)

1st print

2nd and later print

The mean crash rate $\bar{x}$ and sample standard deviation σ_s for the comparison group is calculated. Any rate greater than C in Equation 6.3 below can be considered to be "extremely high."

$$C = \bar{x} + (Z \cdot \sigma_s) \quad (6.3)$$

Because of the variability of the data being analyzed, a confidence level needs to be specified. Most often, a 95 percent confidence level is chosen. The Z value that corresponds to a 95 percent confidence level is 1.96.

Example 6.3

The intersection of Wyckliffe Boulevard and Kolfax Avenue has had 9.35 collisions per million entering vehicles (MEV) during the last 3 years. The crash rate for rear-end collisions is 5.7 per MEV. Eight other intersections in Mythaca have characteristics similar to Wyckliffe and Kolfax. Their crash rates for the last 3 years are summarized in Table 6.1. Does Wyckliffe and Kolfax have an unusually high crash rate for total collisions?

TABLE 6.1 Critical Rate Analysis for Example 6.3

Comparison Site	Total Collisions Rate	Rear-End Collisions Rate
1	7.89	2.67
2	9.24	2.56
3	7.09	2.64
4	8.67	4.00
5	7.20	4.36
6	7.93	2.58
7	9.94	4.77
8	6.68	1.97
Mean, $\bar{x}$	8.08	3.19
Sample standard deviation, σ_s	1.129	1.025

6.1 Highway Safety—Data and Analysis 313

Solution to Example 6.3 The mean crash rate $\bar{x}$ for the comparison group is 8.08 crashes per MEV. The sample standard deviation $\sigma_s = 1.129$ is computed by using

$$\sigma_s = \sqrt{\frac{\sum_{i=1}^n (RMEV_i - \bar{x})^2}{n-1}}$$

where n is the number of comparison group members. The denominator uses " $n-1$," because the comparison group is treated as a sample of "all" intersections like those in the comparison group. Using Equation 6.3 with $Z = 1.96$, $C = \bar{x} + (Z \cdot \sigma_s) = 8.08 + (1.96 \cdot 1.129) = 8.08 + 2.21 = 10.29$. Although Wyckliffe and Kolfax has a crash rate higher than all but one of the intersections in the comparison group, its crash rate does not exceed the critical rate set by Equation 6.3. Therefore, it does not qualify as a hazardous intersection based on total collisions.

The mean crash rate $\bar{x}$ for the comparison group is calculated. If the crash rate r for the location of interest is greater than C calculated using Equation 6.3 below, the crash rate r can be considered to be "higher than expected," or hazardous. (FHWA, 1981)

$$C = \bar{x} + Z \cdot \sigma_s \quad \text{where } \sigma_s \text{ is the standard deviation, and } Z = 1.645 \text{ (one-tailed confidence test)}$$

$$C = \bar{x} + Z \sqrt{\frac{\bar{x}}{r} + \frac{1}{2r}} \quad (6.3)$$

Because of the variability of the data being analyzed, a confidence level needs to be specified. Most often, a 95 percent confidence level is chosen. The Z value that corresponds to a 95 percent confidence level in a one-tailed test is 1.645.

Example 6.3

The intersection of Wyckliffe Boulevard and Kolfax Avenue has had 9.35 collisions per million entering vehicles (MEV) during the last 3 years. The crash rate for rear-end collisions is 5.7 per MEV. Eight other intersections in Mythaca have characteristics similar to Wyckliffe and Kolfax. Their crash rates for the last 3 years are summarized in Table 6.1. Does Wyckliffe and Kolfax (Site 9 in the table) have an unusually high crash rate for total collisions?

TABLE 6.1 Critical Rate Analysis for Example 6.3

Comparison Site	Total Collisions Rate	Rear-End Collisions Rate
1	7.89	2.67
2	9.24	2.56
3	7.09	2.64
4	8.67	4.00
5	7.20	4.36
6	7.93	2.58
7	9.94	4.77
8	6.68	1.97
9	9.35	5.70

This problem was rewritten.

8 other sites

Solution to Example 6.3 The mean crash rate $\bar{x}$ for the comparison group (including the location of interest) is 8.22 crashes per MEV. The critical crash rate C is computed by using Equation 6.3 with $Z = 1.645$:

$$C = \bar{x} + Z \sqrt{\frac{\bar{x}}{r} + \frac{1}{2r}} = 8.22 + 1.645 \sqrt{\frac{8.22}{9.35} + \frac{1}{2 \cdot 9.35}} = 9.82$$

Although Wyckliffe and Kolfax has a crash rate higher than all but one of the other intersections in the comparison group, its crash rate (9.35) does not exceed the critical rate (9.82) set by Equation 6.3. Therefore, it does not qualify as a hazardous intersection based on total collisions.

Determining high-crash locations (p.312)

H_0 : Crash rate at the location under consideration in the group is equal to the average rate of the group.

H_1 : Crash rate at the location under consideration in the group is higher than the average rate of the group.

This is a one-tailed test. Why?

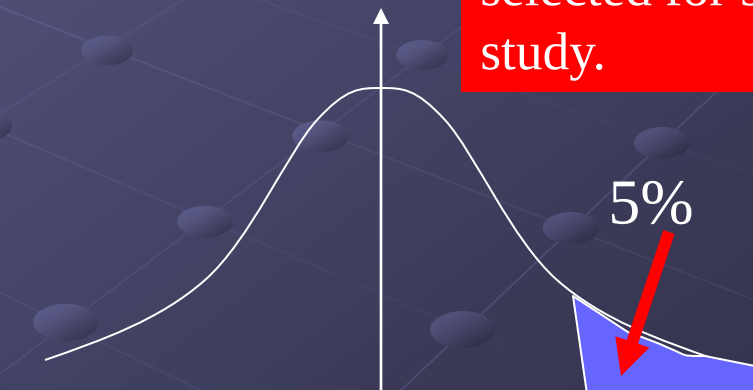
$$z = \frac{x_1 - \bar{x}}{s}$$

$$x_1 \geq 1.645(s) + \bar{x}$$

Example:

Highway Section 33 has 210 crashes/100MVMT. The mean accident rate for the similar classification group = 89 crashes/100MVMT, SD = 64 crashes/100MVMT. Should an analyst flag Section 33 as hazardous with 95% confidence level?

Locations with a higher crashes rate than this value would normally be selected for specific study.



Determining high (or low) -crash locations: Expected value analysis

■ Note this method is used only to compare sites with similar characteristics.

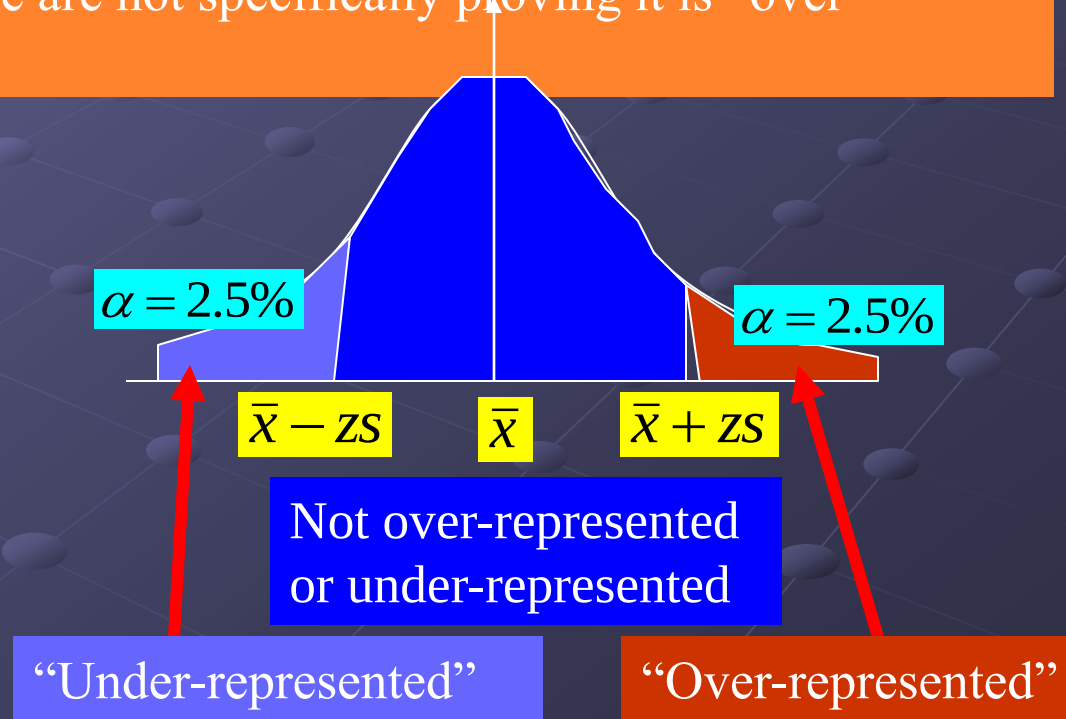
H_0 : Crash rate at the location under consideration in the group is equal to the average rate of the group.

H_1 : Crash rate at the location under consideration in the group is not equal to the average rate of the group (In another words, we are trying to find whether the site under study is “unusual” or not. We are not specifically proving it is “over-represented” or not.)

$$C = \bar{X} \pm Z * S$$

$z = 1.96$ for the 95% confidence level

Locations with a higher crash rate than this value would normally be selected for specific study.



Example: An intersection with 14 rear-end, 10 LT, and 2 right-angle collisions for 3 consecutive years

Control site	Rear-end	LT collisions	Right-angle
1	8	11	4
2	5	12	5
3	7	4	3
4	8	5	6
5	6	8	7
6	8	3	8
7	9	4	4
8	10	9	5
9	6	7	6
10	7	6	7
Mean	7.40	6.90	5.5
SD	1.5	3.07	1.58

□ Check about rear-end collisions

$$EV(\alpha = 0.05) = 7.40 \pm 1.5 \times 1.96 = 4.46 \text{ to } 10.34$$

Rear-end collisions are over-represented at the study site at 95% confidence level, since $14 > 10.34$.

□ Check about LT collisions

$$EV(\alpha = 0.05) = 6.90 \pm 3.07 \times 1.96 = 0.88 \text{ to } 12.92$$

LT collisions are not over-represented or under-represented at the study site at 95% confidence level, since $0.88 < 10 < 12.92$.

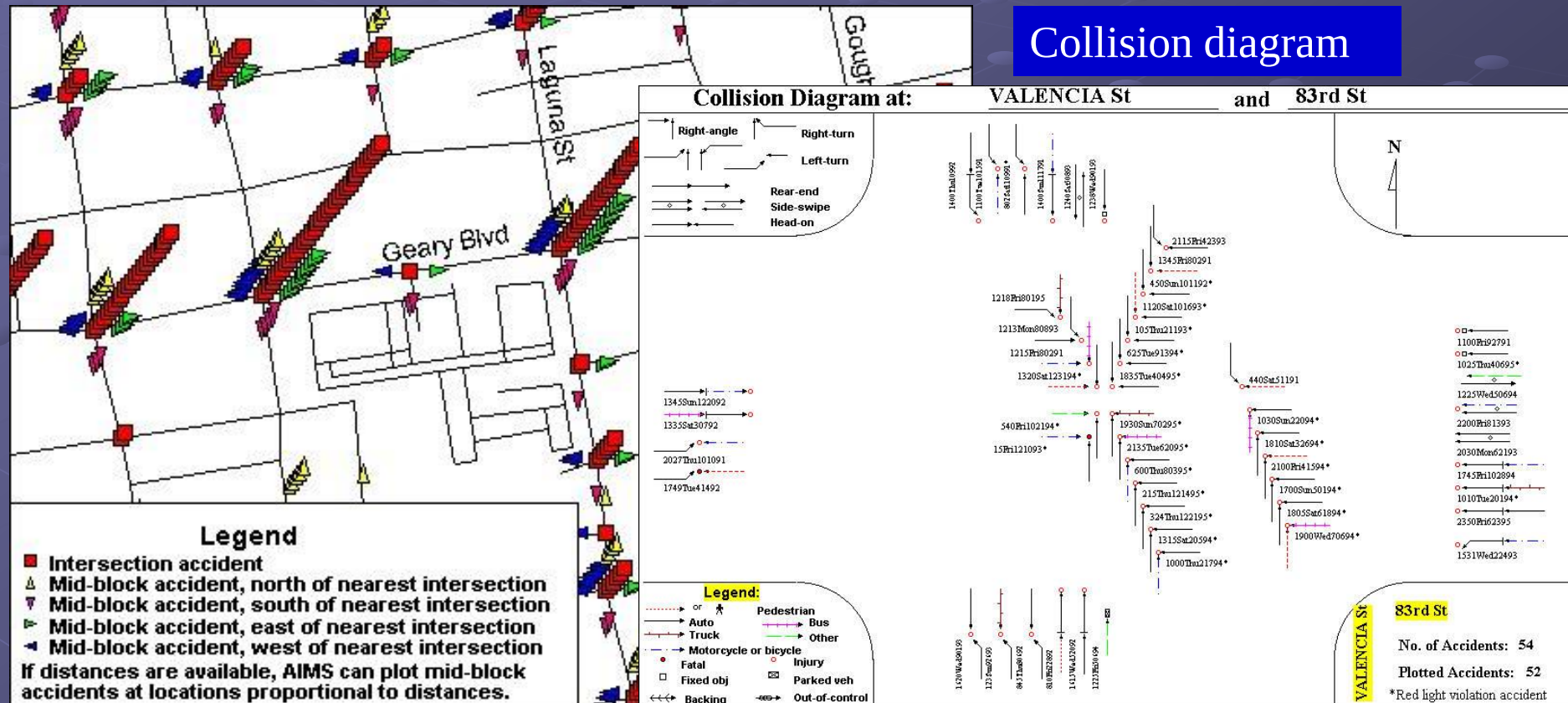
□ Check about right-angle collisions

$$EV(\alpha = 0.05) = 5.5 \pm 1.58 \times 1.96 = 2.4 \text{ to } 10.65$$

Right-angle collisions are under-represented at the study site at 95% confidence level, since $2 < 2.4$.

Planning Component, Process 3: Conducting engineering studies

- One of the most basic functions of traffic engineering is keeping track of the physical inventory.



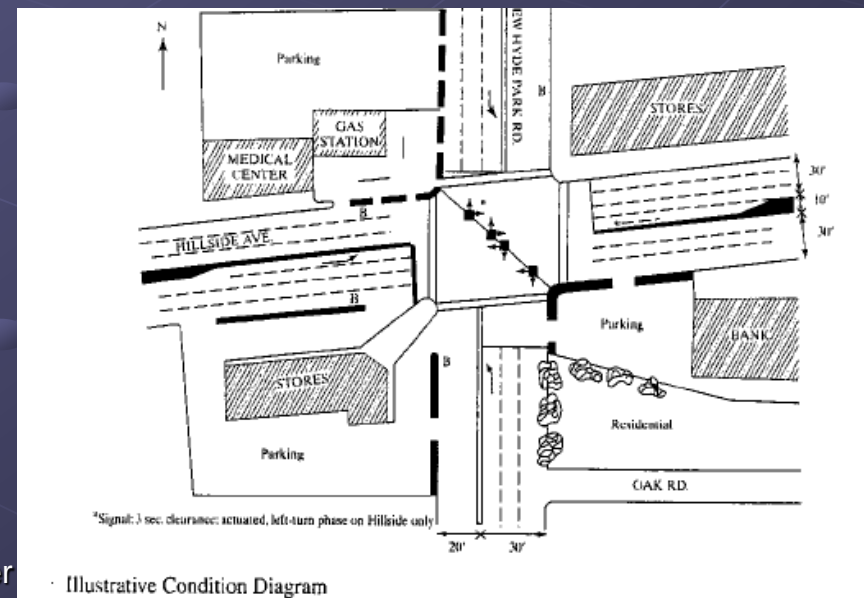
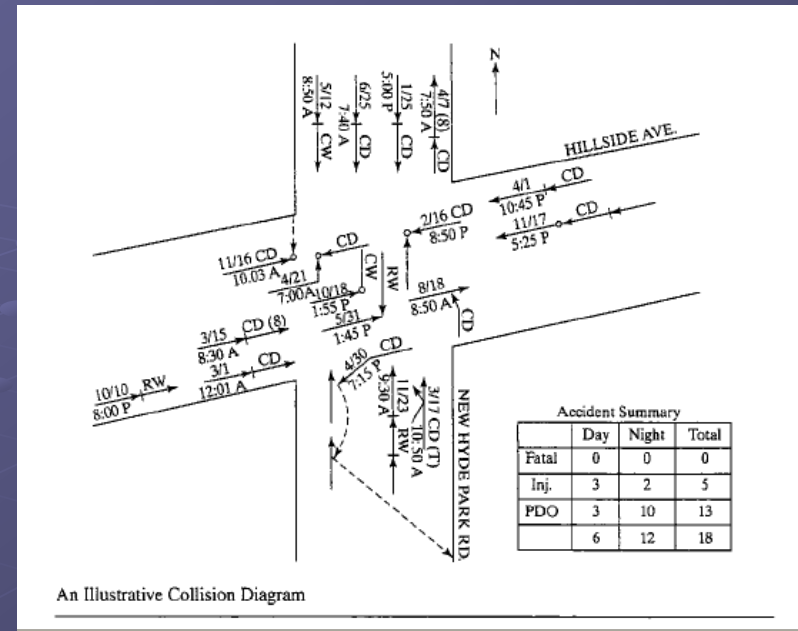
Accident spot map

Planning component, Process 3: Conduct engineering studies

What's in a collision diagram?:

- Type of collision
- Severity
- Contributing circumstances
- Environmental conditions
- Time of day

See Table 6.2 for an example (Right-angle collisions at an unsignalized intersection)



Planning component, Process 4: Establish project priorities

- We need to determine (be able to estimate) the effectiveness of counter measures selected to compare multiple projects for final selection.
- It is extremely difficult to determine the effectiveness of particular countermeasures for certain types of crashes and then convert it to benefits. There are models but not perfect obviously. But this is far better than nothing.

If the effectiveness of a particular countermeasure is known, the following equation can be used to determine its benefit.

$$Crashes_prevented = EC \times CRF \frac{(forecast_ADT)}{(base_ADT)} \quad \text{EQ 6.4}$$

Once the annual crash reduction value is computed, you conduct a more complete analysis including:

- A. The crashes prevented in the years between the base year and the n^{th} year
- B. Years beyond the n^{th} year, if the life of the countermeasure extended that far
- C. An estimate of the cost of the project, spread out over the life of the project

(Crashes prevented over a n-period)

Benefits:

$$\sum_{k=1}^n CP(k) = \sum_{k=1}^n EC * (1+r)^k * CRF$$

Multiply this by the probability of occurrence and \$/crash of each severity type (fatal, PI, PDO)

Costs:

$$PWC = P_0 + A * \left[\frac{(1+i)^n - 1}{i(1+i)^n} \right]$$

6.2 Human Factors and Transportation Engineering

By the end of this section, the student will be able to...

● Objectives of 6.2

- Describe the study of “human factors”.
- Explain how human factors analysis may assist design of transportation systems components

6.2 Human Factors and Transportation Engineering

- Human factors is the study of how human beings function in their natural or constructed surroundings. → Deviation from driver expectation may lead to crashes.

Think About It (p.324) Think of at least one example of a design (good or bad) that has safety consequences and then provide at least two examples of design that causes (or avoids) inefficiency or inconvenience. Your examples do not have to be related to transportation activity.

- Almost 40% of the fatal crashes involve an intoxicated driver.
- The remaining fatal crashes are due to highway design, weather, or “driver error.”
- The road environment contribute to 17 to 34 percent of crashes and is the sole factor in 2 to 3 percent of the cases.
- Inappropriate driver perceptions and behaviors are implicated in 80 to 90 percent of all highway crashes.

The driving task (p.325)

Navigation
(route selection)

Guidance (Vehicle
tracking)

Control (Object avoidance)



This task group involves cognitive and verbal activities: Pre-trip and in-trip phase activities.

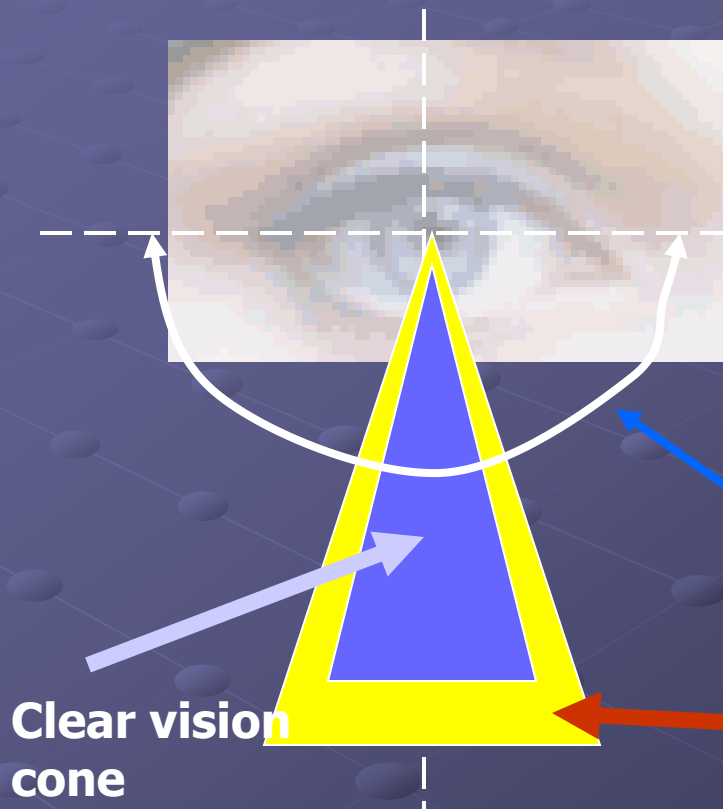
All activities involved in the driver's interaction with the vehicle and its interfaces (control & displays) and with other drivers. Braking and acceleration may be the most frequent tasks of this task group.

The driver's main activities in this task group involve the maintenance of a safe speed and proper path relative to roadway and traffic elements. Guidance activities are characterized by judgment, estimation and prediction within a dynamic, constantly changing environment.

The human response process

Ability to see:

- Static visual acuity
- Dynamic visual acuity
- Depth perception
- Glare vision & recovery
- Color vision
- Peripheral vision (120-180 deg)



**Clear vision
cone**

(3-5 deg)

Fairly clear (10-12 deg)

Perception-Reaction Times (p.328)

PRT = Perception + Reaction

**= (Detection + Identification + recognition) +
(Reaction time needed to initiate the physical response)**

**PIER or PIEV = Perception + Identification
+ Emotion + Reaction (or volition)**



**PIER = f (Complexity of the task,
Level of expectancy,
Variability of the drivers)**

(Read the example
in page 329.)

[Reaction Time Website](#), click here

Distance traveled during PRT

$$\text{Reaction Dist. (ft or meter)} = \text{Speed (ft/sec or m/sec)} * \text{PRT (sec)}$$

How far does the car travel during the perception-reaction process? → Affects sight distance requirement, sign placement, signal timing, etc.

Example: Is this frog in crisis?

65 mph



190 ft away



What was that?

PIEV = 2.5 sec

Speed = 65 mph = $65 \times (5280 \text{ ft} / 3600 \text{ sec}) = 95.55 \text{ ft/sec}$

Distance traveled during PIEV = $95.55 * 2.5 = 238.9 \text{ ft} > 190 \text{ ft}$

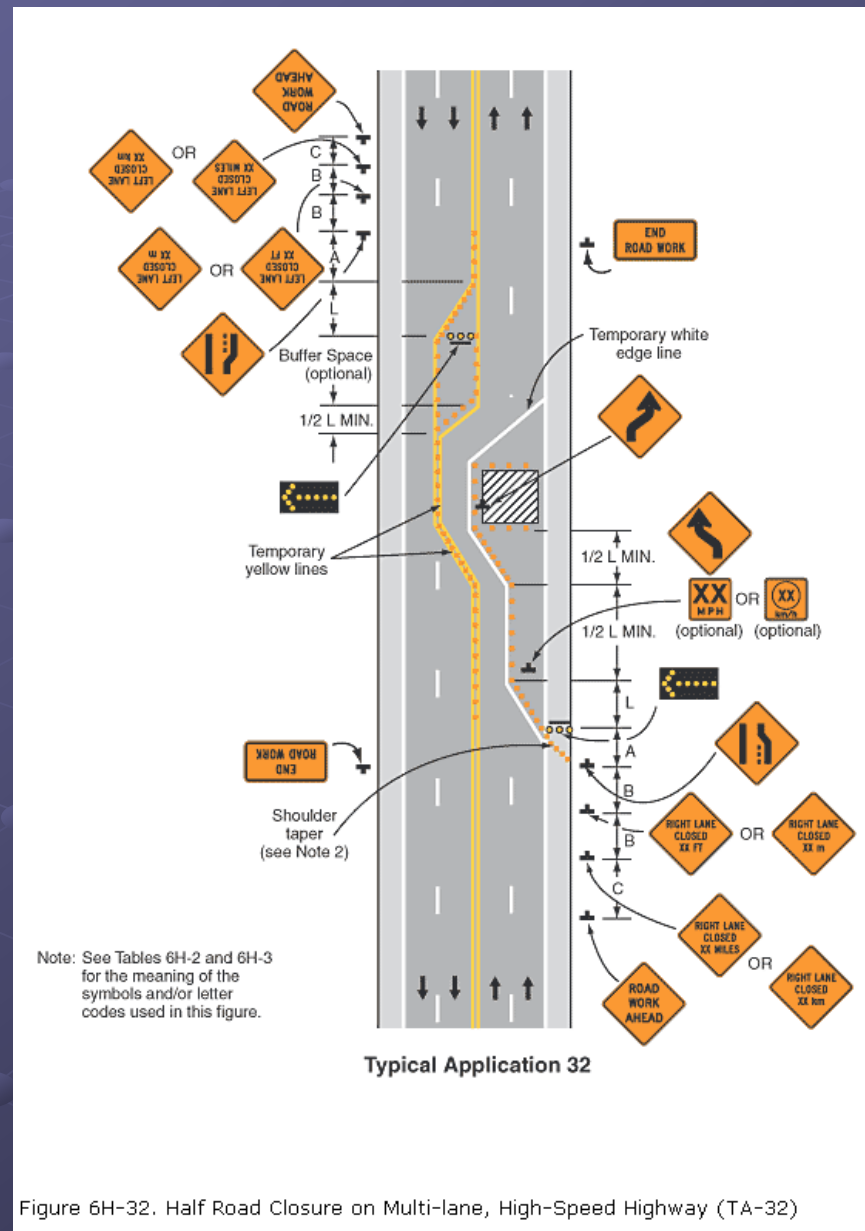
6.2.2 Human factors applications in transportation

There are several recent examples of human factors applications in transportation. Read them to learn the difficulty of dealing with humans. Some people quickly become impatient and non-law abiding when they are in their cars.

We will discuss a couple of them as time permits.

- ❖ License plate design and law enforcement
- ❖ Driving with distractions

“License plate design and law enforcement” section will be helpful to do one of the assignments.



6.3 Vehicle attributes that affect safety

By the end of this section, the student will be able to...

● Objectives of 6.3

- Carry out fundamental calculations related to vehicle performance characteristics.
- Explain how human factors and vehicle performance are the principal factors to consider in highway design.

6.3 Vehicle attributes that affect safety

Acceleration capability and braking capability are the two important vehicle attributes that affect safety. In this section braking capability is emphasized.

6.3.1 Forces acting on automobiles (Deriving the formula to determine braking distance), p.340

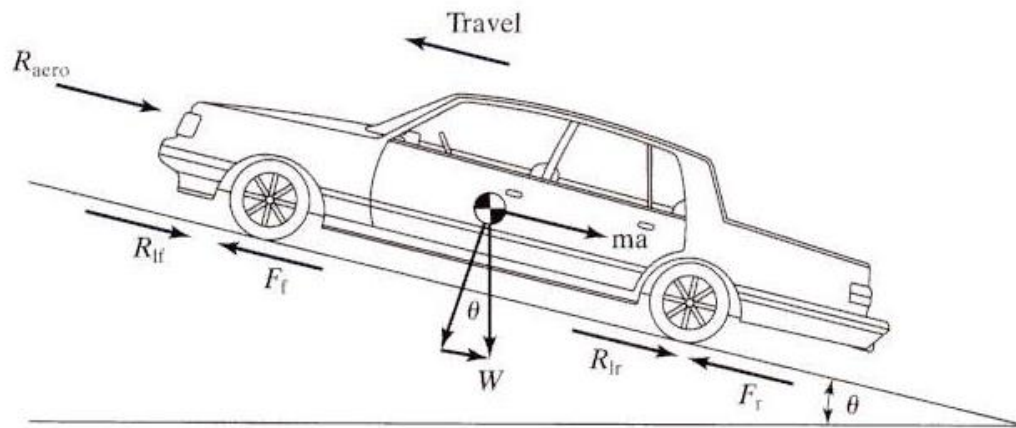


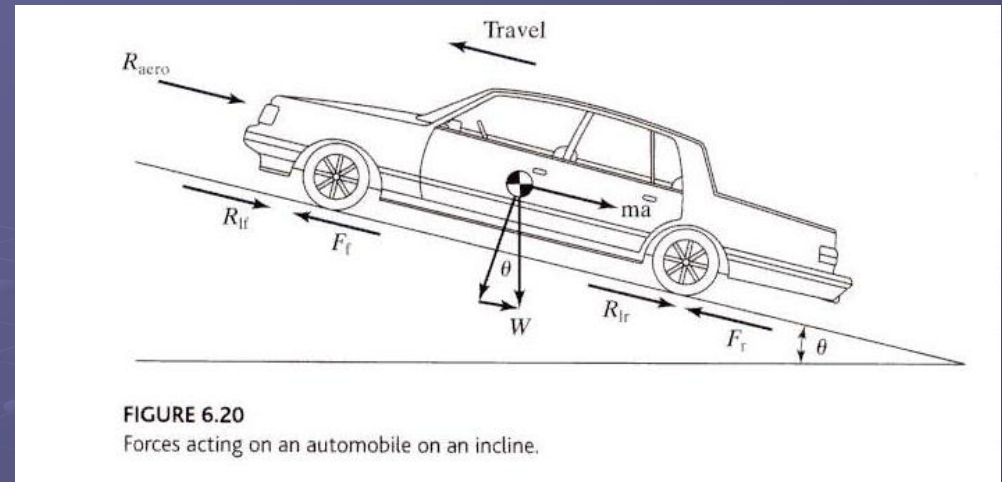
FIGURE 6.20
Forces acting on an automobile on an incline.

$$\begin{aligned} D_{br} &= \frac{v_o^2 - v_f^2}{2g(f \pm \tan \theta_g)} = \frac{v_o^2 - v_f^2}{2g(f \pm G)} \\ &= \frac{v_o^2 - v_f^2}{2g\left(\frac{\alpha}{g} \pm G\right)} = \frac{v_o^2 - v_f^2}{2g(0.35 \pm G)} \end{aligned}$$

Deriving the braking distance formula (continued)

Forces acting on this free body is at equilibrium:

$$\frac{W}{g} a + W f_r \cos \theta + W \sin \theta = 0$$



a is unknown. We want to use the known values (initial speed v , and distance traveled x) to determine a . We assume first the vehicle accelerated at a constant acceleration rate from speed 0 to u .

$$x = \frac{1}{2} a t^2 \text{ \& } v = a t$$

Now $t = v/a$. Plug in this in the RHS of x

$$x = \frac{1}{2} a t^2 = \frac{1}{2} a (v^2/a^2)$$

Now, we get: $x = (1/2)(v^2/a)$

Solve for a : $a = \frac{v^2}{2x}$

It's deceleration, so add -.

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

Deriving the braking distance formula (continued)

The braking distance is a horizontal distance (do you know why we use a horizontal distance?) while x is the distance along the slope; therefore,

$$D_b = x * \cos\theta \quad x = D_b / \cos\theta$$

$$-\frac{v^2}{2g} * \frac{\cos\theta}{D_b} + f \cos\theta + \sin\theta = 0$$

$$-\frac{v^2}{2g} * \frac{1}{D_b} + f + \tan\theta = 0$$

$$\frac{v^2}{2g} * \frac{1}{D_b} = f + G$$

$$D_b = \frac{v^2}{2g(f + G)}$$

$$\frac{W}{g} a + W f_r \cos\theta + W \sin\theta = 0$$

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

Divide both sides by W before obtaining D_b .

One step before Eq. 6.14.

The horizontal distance traveled in reducing the speed from v_o to v_f

Derivation of Eq. 6.14



v_1

D_b for v_o

Speed 0



v_2

D_b for v_f

Speed 0

$D_b = \left[\frac{v_o^2}{2g(f \pm G)} \right] - \left[\frac{v_f^2}{2g(f \pm G)} \right]$

6.3.2 Vehicle Braking (6.3.3 Stopping sight distance)



Sight distance: The length of the roadway a driver can see ahead at any particular time.



The sight distance has to be long enough such that when a driver is traveling at the highway's design speed, adequate time is given, after an object is observed in the vehicle's path, to make the necessary evasive maneuvers without colliding with the object.

Stopping sight distance



SSD = Minimum sight distance required for a driver to stop a vehicle after seeing an object in the vehicle's path without hitting that object.

$$\text{Stopping Sight Distance} = vt + \frac{v^2}{2g(f \pm G)}$$

OR

Distance traveled during the
PIEV time

$$\text{Stopping Sight Distance} = vt +$$

Braking distance

$$\frac{v^2}{2g(a/g \pm G)}$$

Friction coefficients

Friction coefficient varies depending on pavement material and moisture on pavement.

AASHTO recommendation of 0.35 is a conservative value.

(We will work out couple of SSD examples in class. We will skip Example 6.11 because you have to know how to derive formulas for a non-constant acceleration case.)

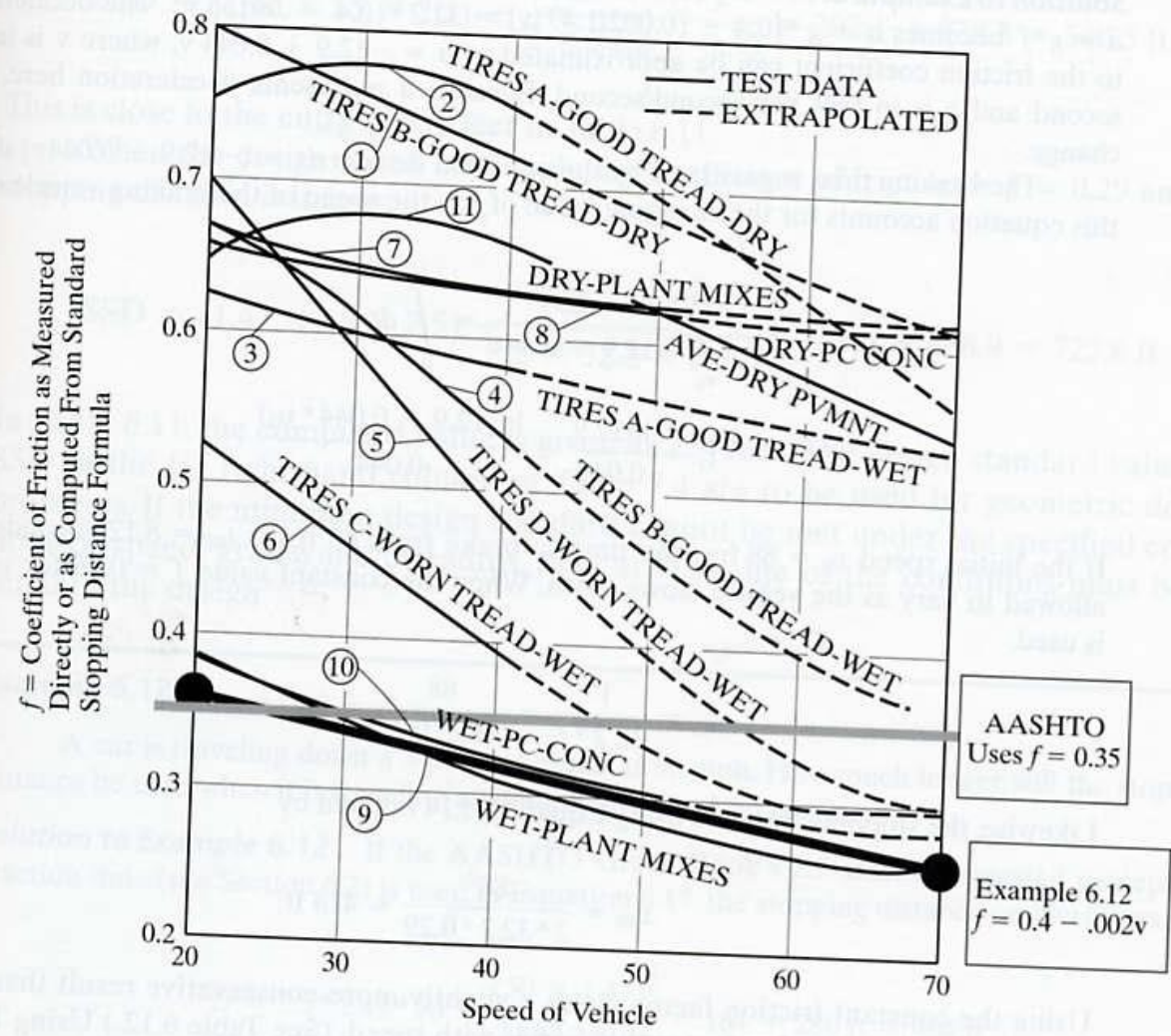


FIGURE 6.21 Skid resistance for various tire and pavement conditions. Source: AASHTO, 1990, Figure III-1.

6.4 Traffic control devices

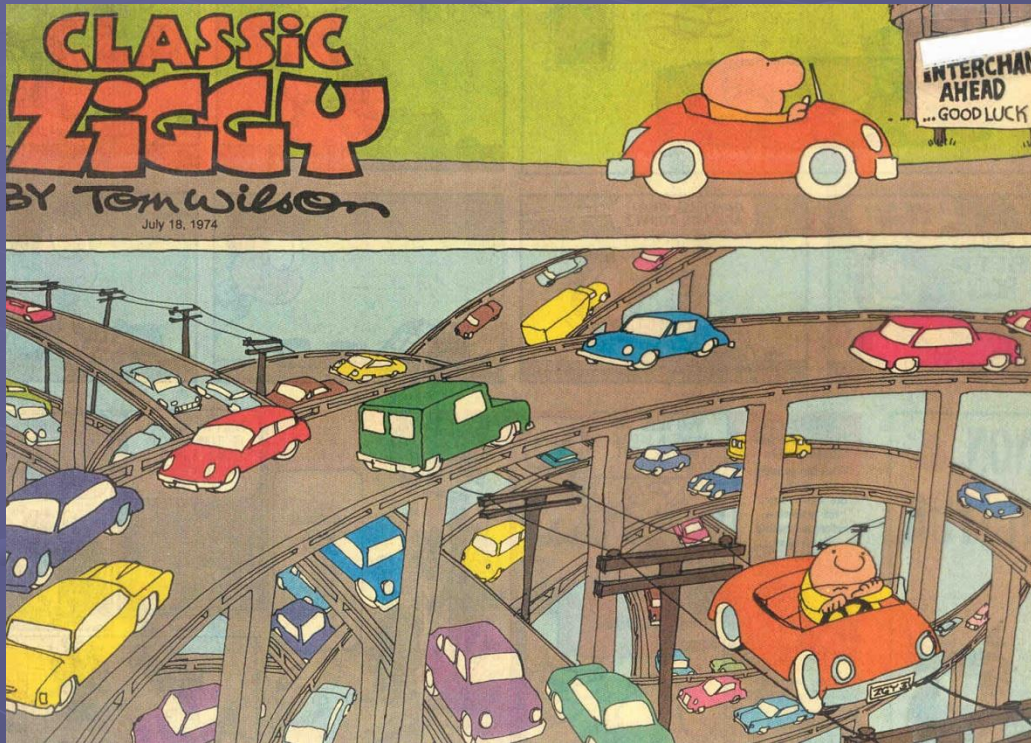
By the end of this section, the student will be able to...

● Objectives of 6.4

- Classify traffic control devices using several criteria
- Distinguish correct TCD installation from incorrect TCD installation.

6.4 Traffic control devices

6.4.1 TCDs needed for safety



We need to avoid this type of confusion..

6.4.2 Rules governing traffic control devices

Manual of Uniform Traffic Control Devices (MUTCD) – federal level guidelines

“The purpose of traffic control is to assign the right of way to drivers and thus to facilitate highway safety by ensuring the orderly and predictable movement of all traffic on highways.”

Control may be achieved by using **traffic signals, signs, markings, or markers** that **regulate, guide, warn, and/or channel** traffic. → MUTCD provides guidelines for determining whether a particular control type is suitable for a given location; it also provides details on the size, color, shape, and legends, if necessary, and location for a particular control type.



MUTCD (cont)



Five requirements to make a traffic control device effective:

- Be needed → Place a proper one, place only the one needed
- Command attention → Make it stand out by color, shape, etc.
- Convey a clear simple meaning → Do not confuse the driver by wordy legends. Give only one instruction by device.
- Command the respect of road users → When you place it, you really mean it.
- Give adequate time for proper response (Be placed to get the proper response from the driver) → Make it visible well in advance of the decision point

Factors to consider for placement of traffic control devices to ensure these five requirements above: Design (size, color, shape), Placement (within cone of vision, consistency in use), Operation (consistent and uniform usage), Maintenance (maintain legibility), and Uniformity (respond to drivers' expectation).

6.4.3 Signs as TCDs & 6.4.4 Roadway markings as TCDs

Before talking about signs and markers, let's talk about the positive guidance concept using the STOP sign.

High speed facilities need larger sizes.

Size

Color

Uniformity in the use of red color alerts the driver.

Shape

The driver can identify this sign from the back, too.



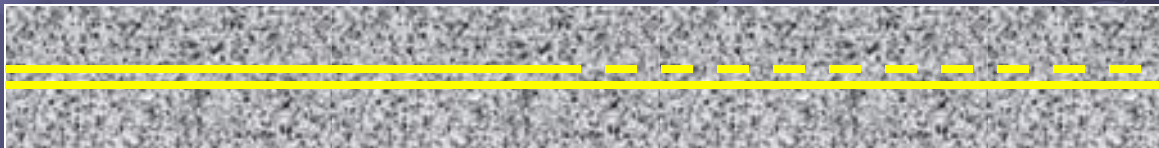
Legend

The legend is simple and obvious.

Redundancy of message can be achieved in a number of ways.



Pattern



These ideas are all based on the “positive guidance” concept.

Positive guidance



Positive guidance is based on the premise:

“Competent drivers can be given appropriate information about hazards and inefficiencies to avoid errors”

Positive Guidance combines highway/traffic engineering and human factors methods and procedures to help produce a highway information system matched to driver attributes and situation demands.



Driver errors focused by positive guidance



- ❖ Excessive task demands
- ❖ Unusual maneuvers or task requirements
- ❖ Poor forward sight distance
- ❖ Expectancy violations
- ❖ Too much processing demand (too stressful)
- ❖ Too little processing demand (gets bored & sleepy)
- ❖ Deficient, ambiguous, confusing, or missing displays
- ❖ Misplaced, blocked, or obscured displays
- ❖ Small, illegible, or inconspicuous displays

Bad
Design

Bad
Operation

Specific information display techniques

Spreading	Reduce the chance of overload at high processing demand locations by moving lower primacy information sources upstream or downstream
Coding and chunking 	Coding: Translates verbal information to drivers into symbols (Color, shape, and number) Chunking: Merging two or more codes into larger units
Repetition	Repeat the same information in the same format (A subset of redundancy)
Redundancy	Give the same kind of information in more than one way or more than one carrier
Navigation information presentation aids	Mid-block signs, trailblazers (with the “TO” sign) Navigation aids like variable message signs ITS – in-vehicle navigation equipment, kiosks, etc.

Traffic signs

Regulatory



Convey information about a specific traffic regulation with which drivers must comply

- ROW series
- Speed series
- Movement series
- Pedestrian series
- Miscellaneous series

Warning



Provides information on impending conditions that are or may be hazardous

11 types: Change in horizontal alignment, Intersections, Advance warning of control devices, Converging traffic lanes, Narrow roadways, Changes in highway design, Grades, Roadway surface conditions, Railroad crossings, Entrances and crossings, miscellaneous

Guide



Provide information to assist drivers in selecting appropriate routes to their desired destinations

- Route markers
- Destination signs, Conventional roadways
- Destination signs, Expressways and freeways
- Service guide signs
- Mileposts



Notes on warning signs

Posting distances

Must provide sufficient PIEV time.

- ❖ Condition A: Difficult judgments are required. $PIEV = 10$ sec.
- ❖ Condition B: May require the driver to come to a full stop before the hazard is reached. $PIEV = 3$ sec.
- ❖ Condition C: Call for drivers to decelerate to a specific advisory speed. $PIEV = 3$ sec.
- ❖ Animal crossings, etc. Place them at the most appropriate locations and repeat them to call attention.

Advisory speed panels

Whenever the safe speed through a hazard is at least 10 mph less than the posted speed limit, a warning sign should be accompanied by an advisory speed panel. Use them in conjunction with a warning sign.



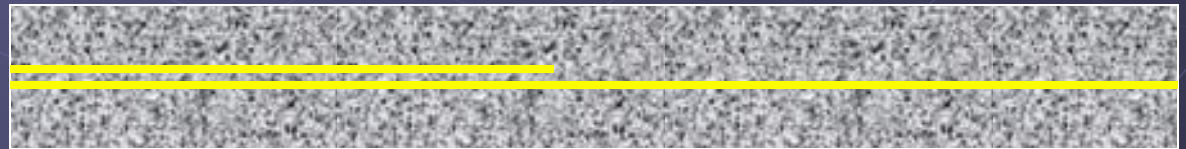
Traffic markings – purposes and placement

Purposes:

- Provide the public with a multiple message with appropriate redundancy and reinforcement of other controls (e.g., no-passing zones)
- In some applications in their own right (e.g., lane marking itself)



Placement:



- Placed directly on the pavement
- Reflectorized if they must be visible at night unless adequately illuminated

Traffic markings – patterns and colors

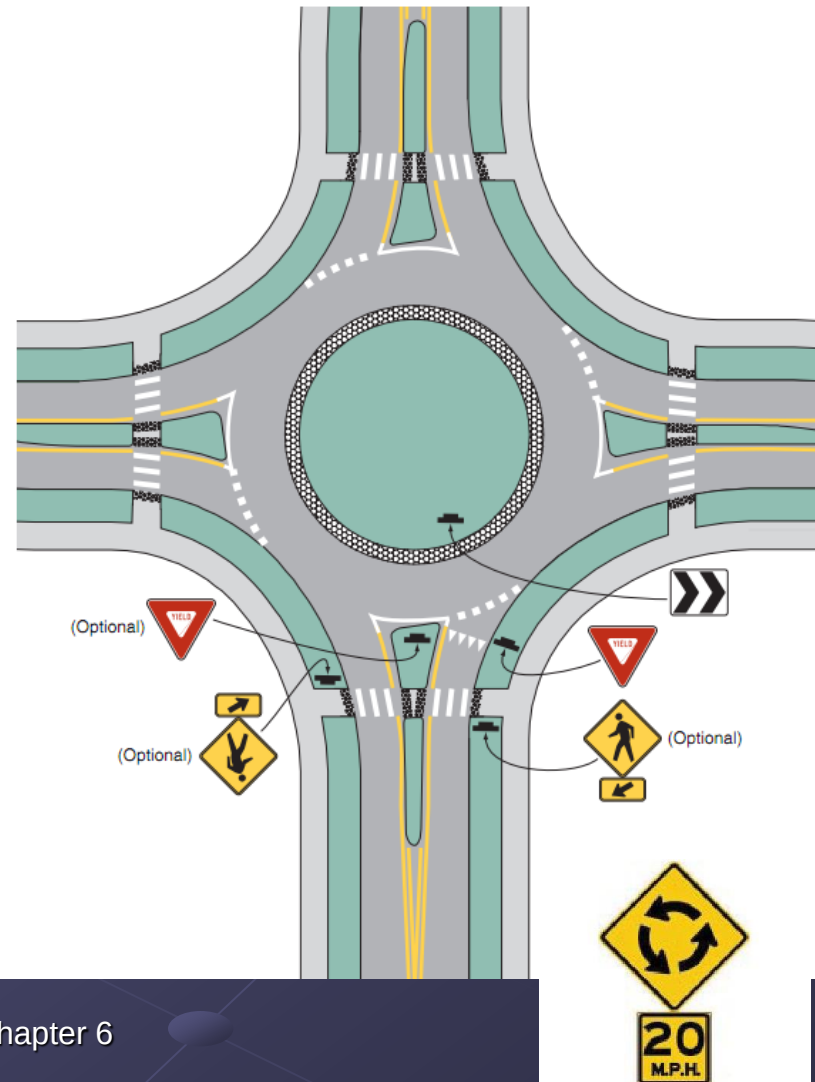
Patterns	Solid line: Identify the road boundaries and delineate the space reserved for the traffic in a given direction Dashed line: Delineate but allow lane changing Levels of restrictions: Dashed line → permissive, Solid line → restrictive, Double lines → maximum restriction
Colors	Yellow → Separate flow directions White → Separate lanes in the same direction Red → Delineate roads that shall not be entered Black → Combined with other, if needed, for contrast (Have you seen recent I-15 center lines?)

Typical markings for roundabouts with one lane



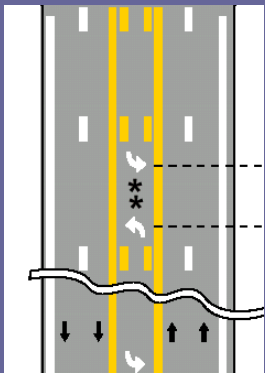
Example of an incorrect signing at a roundabout in Lehi (Main at 500W)

Figure 2B-22. Example of Regulatory and Warning Signs for a One-Lane Roundabout



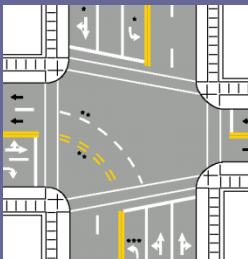
Types of lines

Longitudinal
(Fig. 14-2 and 3,
And Fig. 14-7)



1. A normal, broken white line
2. A normal, broken **yellow** line
3. A normal, solid white line (Crossing discouraged)
4. A double solid white line (Crossing prohibited)
5. A double line consisting of a normal, broken **yellow** line and a normal, solid **yellow** line
6. A double line consisting of two normal solid **yellow** lines
7. A double, normal, broken **yellow** line
8. A normal dotted line (the same color as the line it extends)
9. A solid **yellow** line

Transverse
(Fig. 14-4, etc)

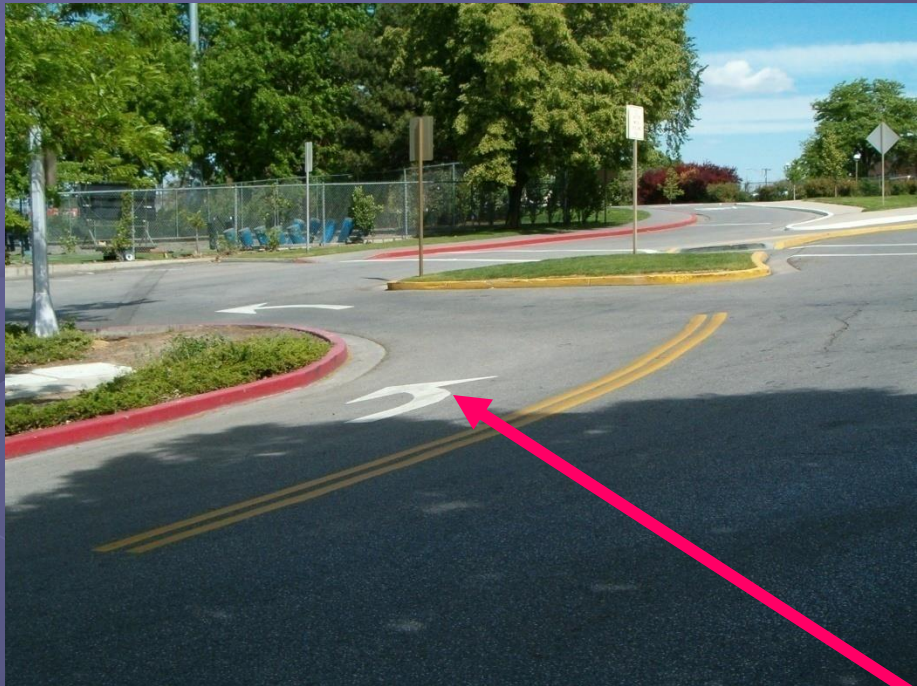


- Shoulder markings, word & symbol markings, stop lines, crosswalk lines, parking space markings, etc. → **White**
- Transverse edge lines for crosswalk near school buildings and grounds → **Yellow**
- Markings visible to only those in the wrong direction may be → **Red**

Curb markings

Delineation and parking regulations → **Red** and **White**

Incorrect pavement marking example on BYU campus: an example (This was finally corrected. Now it's a double solid white line.)

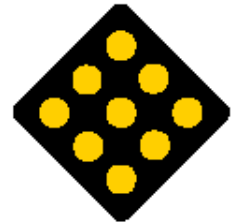


Do you know where this is located?

In the other side of the double-solid yellow line vehicles are traveling in the opposite direction! That's what you expect.

Markers – three types

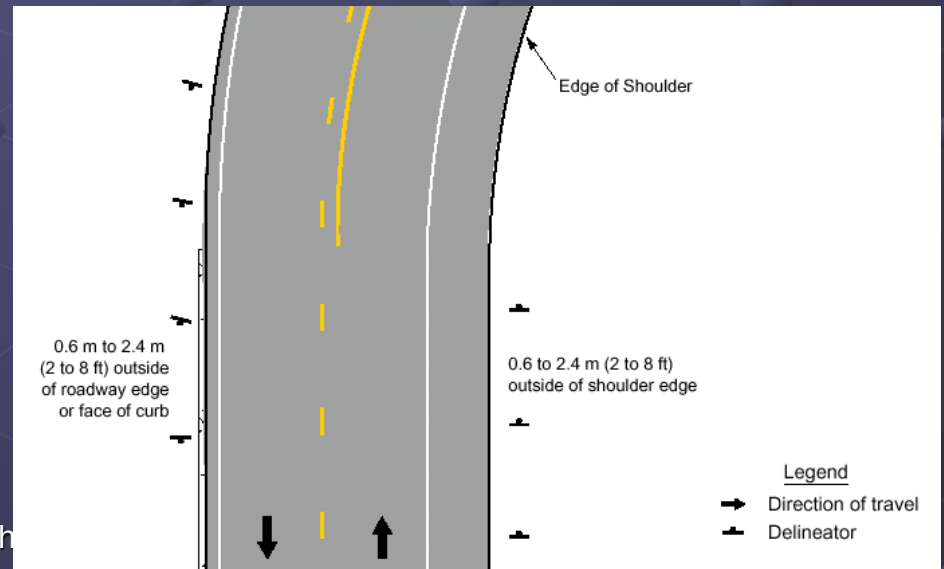
- ☀ Raised pavement markers → functions like pavement markings.
- ☀ Object markers → usually placed on a pole, showing there is an object behind it.
- ☀ Delineators → shows pavement edges or edge of roadways



OM1-2



This is an example of incorrect placement.



6.4.6 Stop signs for speed control

(Actually it is not recommended to use stop signs for speed control. They are meant for reducing crashes by allocating the right of way. Better use traffic calming strategies for speed control.)



Speed bumps



Roundabouts



Entryways



Chokers

Example 6.15 Comparing two mean speeds (FYI) – We will do this more in CE562

● This test is done to compare the effectiveness of an improvement to a highway or street by using mean speeds.

- If you want to prove that the difference exists between the two data samples, you conduct a two-way test.

Null hypothesis $H_0: \mu_1 = \mu_2$

Alternative $H_1: \mu_1 \neq \mu_2$

- If you are sure that the measure taken would improve the performance of the highway or street, you conduct a one-way test.

Alternative $H_1: \mu_1 > \mu_2$

Comparing two mean speeds (cont)

Step 1: Find mean and SD of the two samples

$$\bar{u}_{EB} = 23.41 \text{ mph} \quad \bar{u}_{WB} = 22.56 \text{ mph}$$

$$S_{EB} = 3.84 \text{ mph} \quad S_{WB} = 2.84 \text{ mph}$$

$$n_{EB} = 39 \quad n_{WB} = 34$$

Step 2: Compute the standard deviation of the difference in means
(Assumes S_1^2 and S_2^2 are similar) – “pooled data” – the z score

$$S_d = \text{SQRT}(S_{EB}^2/n_{EB} + S_{WB}^2/n_{WB}) = \text{SQRT}(3.84^2/39 + 2.84^2/34) = 0.78$$

$$Z = (\bar{u}_{EB} - \bar{u}_{WB})/S_d = (23.41 - 22.56)/0.78 = 1.09$$

Step 3: Test the hypothesis. If computed $z < \pm 1.96$, accept the null hypothesis.

Computed $z = 1.09 < z = 1.96$ for a 95% confidence level.

Hence, it can be concluded that the difference in mean speeds is not significant at the 95% confidence level. (In this case stop sign does not help reduce the speed.)