Intersection Safety

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Intersection Safety

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I. Introduction

Intersection Safety is an important issue because nationally there are:

- 3 million intersections
- 2.7 million un-signalized intersections
- 300,000 signalized intersections
- 9,612 intersection fatalities per year
- $101 billion annual cost of intersection crashes

Despite improved intersection design and more sophisticated applications of traffic engineering measures, the annual toll of human loss due to motor vehicle crashes has not substantially changed in more than 25 years.

As seen in the following illustration, there were 17 states that had high road fatality rates per population. This represents 33% of the states.

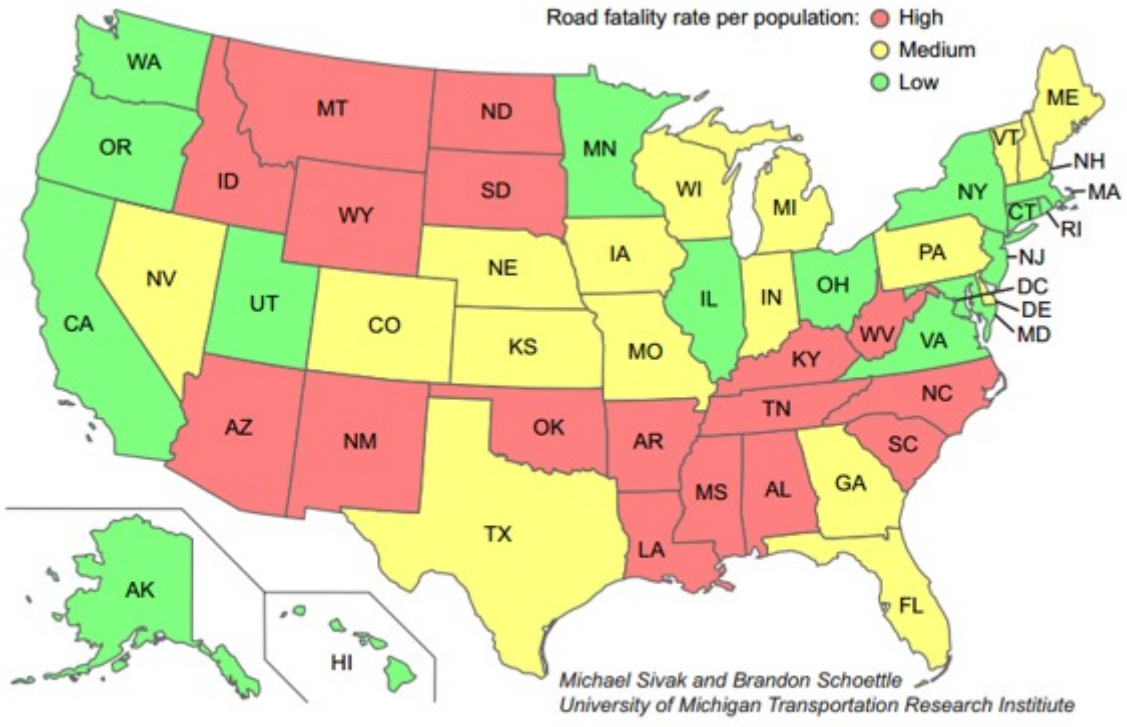
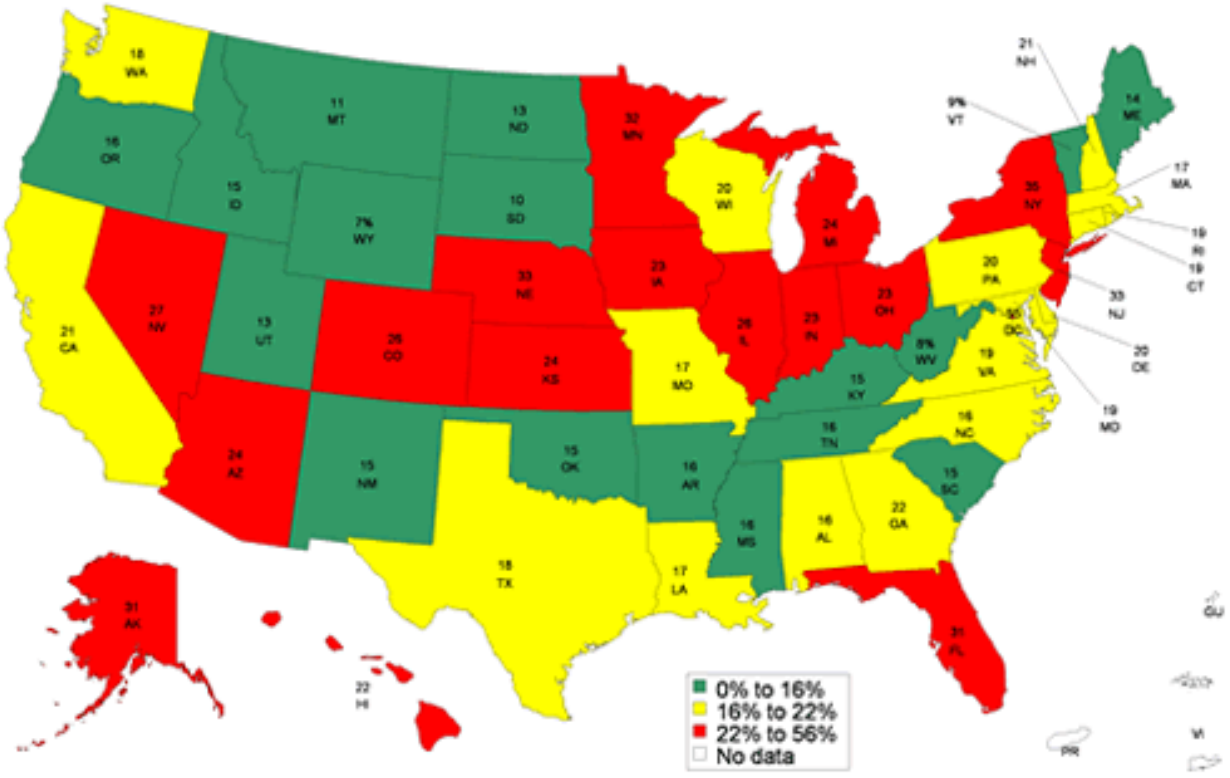


Figure 2. Fatality rate from road crashes per population, 2013.

Intersection safety is a national, state and local priority. Intersections represent a disproportionate share of the safety problem. As a result, organizations such as the Federal Highway Administration (FHWA), Institute of Transportation Engineers (ITE), AASHTO, AAA and other private and public organizations are devoting resources to help reduce the problem.

The following illustration shows the percentage of fatalities vs. crashes at intersections by state.



A. Intersection Crash Characteristics

Over the past two decades, urban intersectional vehicle crashes have increased 14%. A total of 55% of all urban vehicle crashes occur at intersections. Also, 23% of urban fatal crashes occur at intersections.

Over the past two decades, rural intersectional vehicle crashes have increased 5%. A total of 32% of all rural vehicle crashes occur at intersections. Also, 16% of rural fatal crashes occur at intersections.

The following table shows the difference in the percentages of crash types between yield/stop and signalized intersections.

Type of Control	Accident Type – Percent of Total				Accident Rate (accidents per million entering vehicles)
	Rear-End	Angle	Sideswipe	Other	
Traffic Signal	43	37	12	8	1.26
Yield or Stop Sign	29	49	10	12	1.08

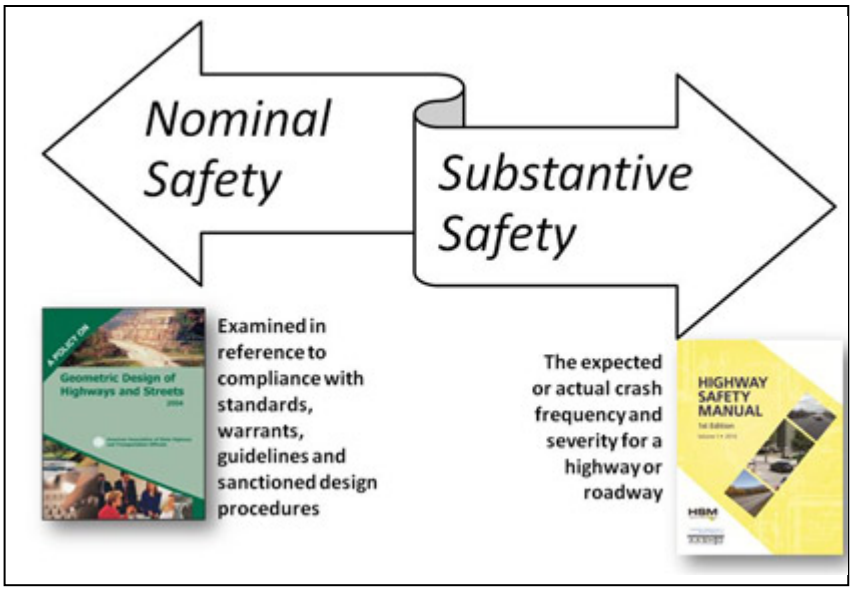
As the table shows, the rear end crashes increase at the signalized intersection (14% increase). However, these types of crashes are generally less severe. The angle crashes also decrease at a signalized intersection (12% decrease). These types of crashes are generally more severe. Thus a signalized intersection can reduce the severity of the crashes.

B. Link between Standards and Safety

Meeting design standards does not necessarily make a highway safe. Important features of highways are often not determined by standards.

- *Nominal Safety* is examined in reference to compliance with standards, warrants, guidelines and sanctioned design procedures. Nominal safety devices can consist of advance warning signs and conventional road size.

- *Substantive Safety* is the actual crash frequency and severity for a highway or roadway. It is measured by actual frequency and severity. Substantive safety devices can consist of oversized signs, double placement of signs and yellow flashers with signs.



II. Human Factors

Both the number and severity of crashes are impacted by how a particular intersection is built and how it is operated. Design can reduce:

- Incidence of human error
- Chance of human error resulting in crash
- Severity of the consequences of crashes

Research indicates that driver error may account for approximately 90 percent of all crashes. While advances in automotive safety and highway design continue to improve, the one component that has not changed is the driver. Understanding how drivers and all roadway users interact within an intersection environment is fundamental to improving roadway safety and saving lives.

To successfully execute a vehicle maneuver through an intersection, the driver must assimilate the information, make a decision and execute the desired action. One limitation is that humans are serial processors and the cognitive task-load at intersections can be quite large. Common items a driver must consider when approaching an intersection include:

- Monitoring and adjusting speed
- Maintaining lane position
- Being aware of other vehicles
- Attending to signals or signs
- Scanning for pedestrians/bicyclists
- Decelerating for a stop
- Searching for path guidance
- Selecting proper lane

Human Factors and Their Relationship to Roadway Design Elements		
Human Factor	**Design Value**	**Design Element Affected**
Perception-reaction time	1.0-2.5 sec.	Stopping Sight Distance
Deceleration rate	11.2 ft/sec.^{2}	Stopping Sight Distance
Pre-maneuver (distance to detect an unexpected condition)	3.0-9.1 sec.	Decision Sight Distance
Gap acceptance Turning left or right from stop Crossing from stop	 7.5 sec. Minimum 6.5 sec. Minimum	 Stopping Sight Distance Stopping Sight Distance
Driver height of eye	4.25 feet	Stopping Sight Distance
Pedestrian walk times	3.0-4.5 ft/sec	Pedestrian Facilities

A. Driver Error

Perceptual failures account for a large portion of driver errors. Common driver errors for signalized intersections and unsignalized intersections include:

a. Signalized Intersections

- Not understanding whether to proceed or stop at a yellow signal indication (dilemma zone)
- Underestimating time to reach an intersection
- Underestimating time to make a smooth stop
- Failure to detect signal and proper lane assignment
- Misinterpreting guide sign information

b. Unsignalized Intersections

- Unsafe gap acceptance
- Inaccurate estimation of approach vehicles' speed
- Underestimating time to accelerate after making a turn
- Failure to yield right-of-way

III. Predicting Safety of Intersections

Traffic volume is the single greatest predictor of the quantitative risk of a crash for a highway. Collision rates at 4-leg intersections are 1.3 to 1.4 times those at 3-leg intersections. The following equations can be used to calculate the expected crash rates (CR) for different scenarios.

A. Crash Rate for an Intersection

CR = Crash Rate
N = Number of Crashes
Sum (ADTs) = sum of ADT for all approaches

$$CR = N / \{[Sum (ADTs)/2)] \times 365 \times 10^{-6}\}$$

Example Calculation for a Crash Rate for an Intersection

For: N = 25 crashes for 3 years
ADT (N)=4,000, ADT(S)=3,500, ADT(E)=1,500, ADT(W)=2,000
Sum (ADT)s = 4,000 + 3,500 + 1,500 + 2,000 = 11,000

$$CR = N / \{[Sum (ADT)s /2] \times 365 \times 10^{-6}\}$$
$$CR = 25 / \{[11,000/2] \times 3 \text{ yrs} \times 365 \times 10^{-6}\}$$
CR = 4.15 crashes per million entering vehicles

B. Crash Frequency Models for Stop Control of Minor Approaches

a. Three-Leg Stop Controlled Intersection

$$N = e^{(-10.9 + 0.79 \ln (ADT1) + 0.49 \ln (ADT2))}$$

ADT1 = Avg Daily Volume on Major Road
ADT2 = Avg Daily Volume on Minor Road

b. Four-Leg Stop Controlled Intersection

$$N = e^{(-9.34 + 0.60 \ln (ADT1) + 0.61 \ln ADT2))}$$

ADT1 = Avg Daily Volume on Major Road
ADT2 = Avg Daily Volume on Minor Road

c. Four-Leg Signalized Intersection

$$N = e^{(-5.73 + 0.60 \ln (ADT1) + 0.20 \ln (ADT2))}$$

ADT1 = Avg Daily Volume on Major Road
ADT2 = Avg Daily Volume on Minor Road

d. Three-Leg Signalized Intersection

$$N = \{e^{(-10.79 + 0.79 \ln (ADT1) + 1.49 \ln (ADT2)}\} \times \{e^{(-5.73 + 0.60 \ln (ADT1) + 0.20 \ln (ADT2)}\} / \{e^{(-9.34 + 0.60 \ln (ADT1) + 0.61 \ln (ADT2)}\}$$

ADT1 = Avg Daily Volume on Major Road
ADT2 = Avg Daily Volume on Minor Road

Example Problem: Crash Rate Model for Stop Controlled Intersection

Data: Three-leg stop controlled intersection
Major Street ADT = 5,000
Minor Street ADT = 500

$N = e^{(-10.9 + 0.79 \ln (ADT1) + 0.49 \ln (ADT2))}$

$N = e^{(-10.9 + 0.79 \ln (5000) + 0.49 \ln (500))}$

N = 0.324 crashes per year or 1.62 crashes in a 5 year period

Collision rates at a 4-leg low volume intersection are 1.3 to 1.4 times those at a 3-leg intersection. Safety of a 3-leg intersection increases as minor road traffic increases.

C. Gap Acceptance Model (For Stop-Controlled Intersections)

Intersection Sight Distance (ISD) = $1.47 \times V \times t_g$

Where:
V = design speed of major road (mph)
t_g = time gap for drivers on stopped approach (seconds)

D. Severity Index

The severity index (SI) is the ratio of crashes involving an injury or fatality to total crashes.

Accident Severity Level	Proportion of Total Accidents	
	Roadway Segment	Intersections
Fatal and Injury	0.321	0.397
Property Damage Only	0.679	0.603
Total	1.000	1.000

IV. Screening Techniques

Intersections need to be screened from a variety of standpoints to determine if they are safe. Two of the screening measures may include roadway geometrics and traffic operational characteristics.

Is this intersection as safe as it can be? It does not appear to be signal or stop sign controlled. Intersection traffic control is integral to traffic safety.

A. Conventional Screening

Conventional techniques of screening are known to have difficulties in identifying "unsafe" sites:

- Crash counts are bias to high volume sites.
- Crash rates are bias to low volume site.
- Crash rates' assumption of linearity is invalid.
- Regression-to-mean (RTM) effect if ample allowance is not made for random errors.

B. Network Screening

The highway network system is made up of segments and intersections. Network screening is a systematic examination of all entities. The purpose is to rank all entities, based on selected criteria, in order to conduct detailed safety studies.

V. Identification of High Crash Locations, Engineering Studies and Intersection Safety

A. Crash Mitigation Process

There are six steps in the crash mitigation process:

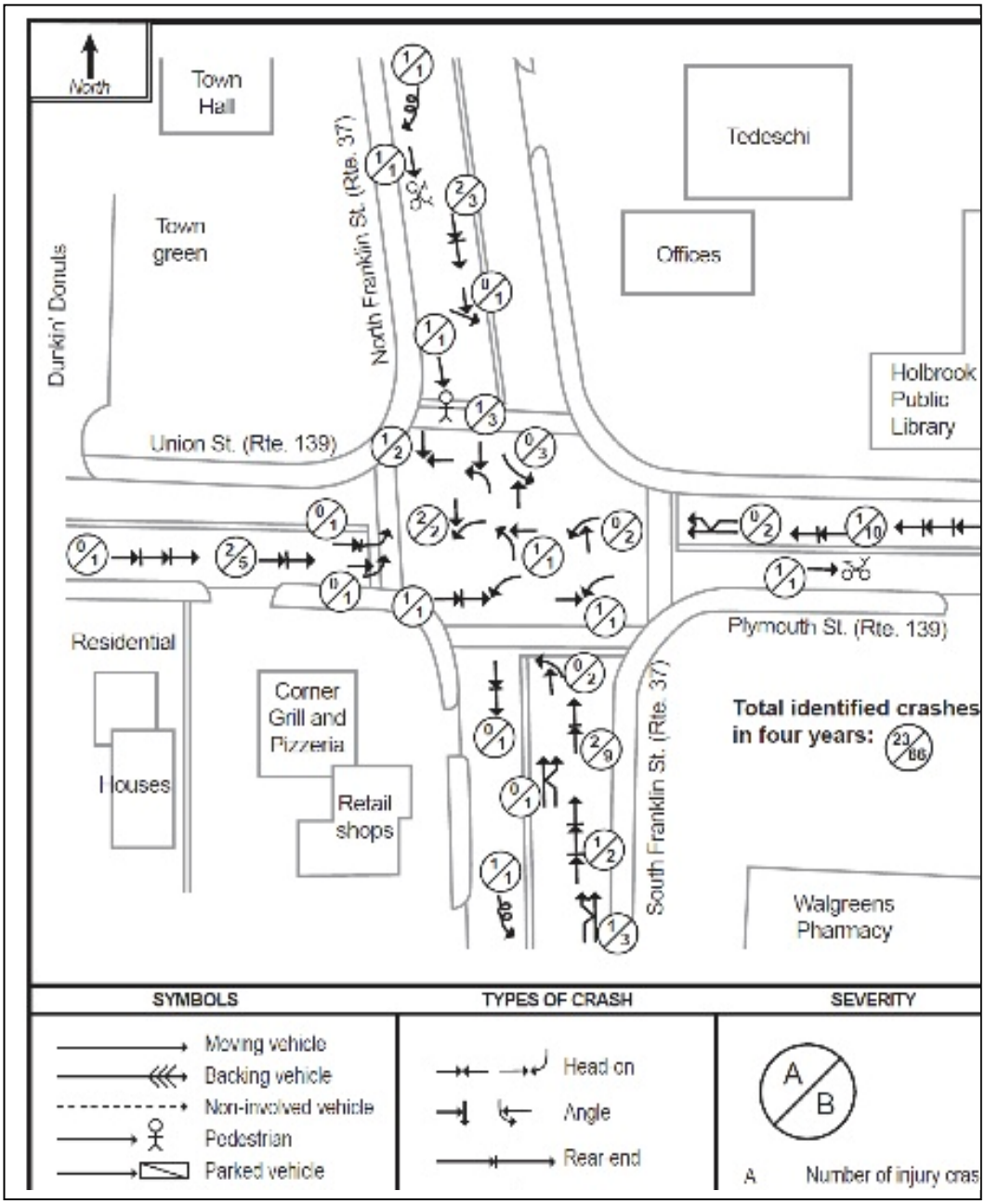
Step 1. Identify Sites with Potential Safety Problems.

A variety of data can be used to determine if a site has a safety problem.

- Crash data
    - Total number of crashes
    - Crash density (crashes per mile)
    - Crash rate (crashes per million vehicle miles)
    - Crash severity
    - Severity index
- Field observations
- Complaints
- Enforcement input
- Maintenance staff input

Step 2. Characterize the Crash Experience

Review the police accident reports for the specific intersection to be analyzed. Define the problem and prepare a collision diagram. The following illustration is a sample collision diagram.



Step 3. Characterize the Field Conditions.

Characterize the field conditions. The study may require traffic data studies:

- Traffic volume (turning movement, ADT, peak hour)
- Spot speeds
- Traffic conflict study
- Sight distance evaluation

Step 4. Identify Contributing Factors and Appropriate Countermeasures.

Identify intersection crash patterns from field reviews, collision diagram or other means of evaluation. Identify potential countermeasures.

Step 5. Assess Countermeasures and Select the Most Appropriate.

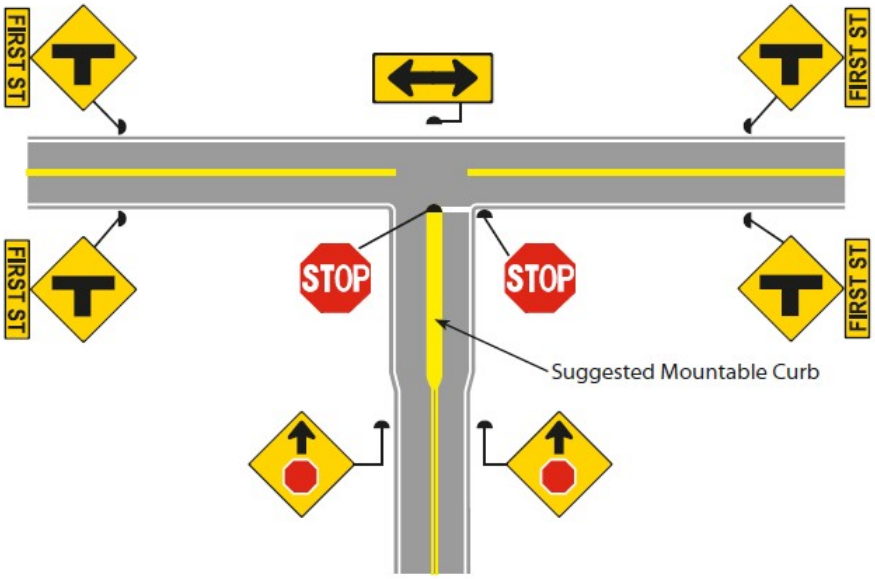
Compare the results of the crash patterns against potential countermeasures. The engineer can develop a matrix of potential countermeasures or documents such as the Institute of Transportation Engineers (ITE) "Toolbox of Countermeasure and Their Potential Effectiveness to Make Intersections Safer" can be used to search for countermeasures for particular crash patterns.

Step 6. Implement Countermeasures and Evaluate Effectiveness.

The following examples represent samples of countermeasure implementation. After implementation, the effectiveness of the countermeasure should be evaluated to see if there is a crash reduction.

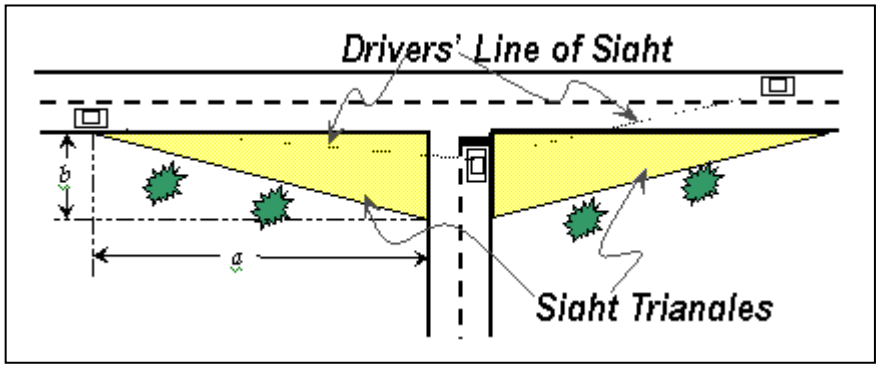
Example of Advance Warning Sign Improvement

The following illustration shows the addition of advance warning signs for cross street names as well as stop signs and ahead signs for a T-intersection.



Example of Sight Distance Improvement

Adequate sight distance for drivers at Stop or Yield controlled approaches to intersections has long been recognized as among the most important factors contributing to overall safety. As an example, improved sight distance can result in a 5% crash reduction per quadrant (20% for all 4 quadrants). The trees and shrubbery have been removed 50’ back from the corner of the intersection.



VI. Intersection Countermeasures

Traffic control devices are signs, signals and pavement markings placed along highways to move vehicles and pedestrians safely and efficiently. These devices are placed in key locations to guide traffic movement, control vehicle speeds and warn of potentially hazardous conditions. They also provide important information to drivers about detours and traffic delays.

A. Stop Controlled Intersection Countermeasures

- Cutback vegetation to intersection sight distance (ISD) values
- Remove sight obstructions of walls, fences, signs
- Establish 50'-50' clear corner sight distance policy/ordinance
- Secure agreements with private property owners
- Restrict parking
- Move stop bars forward to just behind edge of outside lane
- Use advisory speed plaques on approaches
- Reduce posted speed limit on approaches
- Establish all-way stop control per MUTCD

B. Signalized Intersection Countermeasures

- Update yellow clearance timing
- Add all-red clearance phase
- Signal retiming
- Signal phasing and cycle improvements
- Improve visibility (12" sections, etc)
- Add back plates
- Change permissive lefts to protected only
- Add advance warning signs with active flashers
- Add supplemental signal heads
- Use overhead red "T" heads
- Change late night yellow/red flash to full time signal
- Coordination of signals
- Controller/actuation upgrades
- Provide advance detection on the approaches so the vehicles are not in the dilemma zone when the signal turns yellow

Traffic signals are used to assign vehicular and pedestrian right-of-way. They are used to promote the orderly movement of vehicular and pedestrian traffic and to prevent excessive delay to waiting traffic.

Safety Benefit of Signalization

Install New Traffic Signal (ITE/FHWA)
All Crashes - 20-40% reduction in crashes
Right angle crashes – 68% reduction in crashes

Upgrade Traffic Signal
Fatalities – 38% reduction in crashes
Injuries – 22% reduction in crashes

Yellow Clearance Period

The following equation for yellow clearance period can be used to improve signalized intersection safety by modifying the signal timing to increase the time for the dilemma zone.

$CP = t + V / (2a + 2Ag)$

CP = Yellow clearance period
T = reaction time (assume 1 second)
V = 85^{th} percentile speed (ft/sec/sec)
a = deceleration rate of the vehicle (assume 10 ft/sec/sec)
A = acceleration due to gravity (32.2 ft/sec/sec)
G = percent grade (+ for upgrade and – for downgrade)

Example for Yellow Clearance Interval Calculation

or 85^{th} percentile speed of 45 mph on 0% grade

$P = t + V / (2a + 2Ag)$
$P = 1.0 + \{[45 \times 5280 / 60 / 60] / [2 \times 10]\} + (2 \times 32.2 \times 0\%)]$
$P = 1.0 + 66/20 + 0.0$
$P = 1.0 + 3.3$
$P = 4.3$ seconds

C. Regulatory Signing Countermeasures

Right-of-Way Control Countermeasures

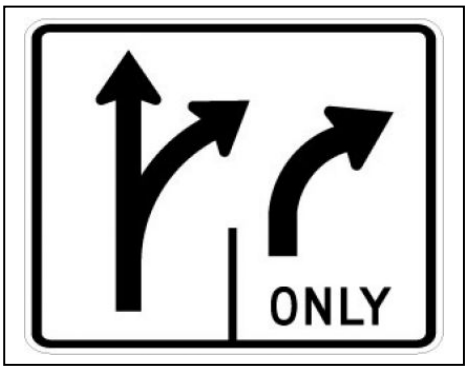
- 1^{st} Step is Nominal Compliance with MUTCD
- Visibility
- Enhanced Emphasis Treatments
- Plaques (included All but one Approach Stop Controlled)

- Change from Yield to Stop Control; 2-Way Stop to All-Way Stop
- Stop Beacons

Lane Use Signing

- At-Intersection
- Advance

Lane use signing can provide a crash reduction factor (CRF) of 30%. The following illustration is an example of lane use signing. Note lane use signs can be ground mounted or overhead mounted for better visibility.



Route Marker Signing

The following illustration is an example of route markers. Note route markers can be ground mounted or overhead mounted for better visibility.

D. Guide Sign Countermeasures

Advance Street Name Signs

The following illustrations is an example of an advance street name sign.

E. Warning Sign Countermeasures

Advance Warning Signing

- for unexpected conditions
- for intersections
- to enhance other advance warning signs
- for right-of-way controls
- flashers for intersection warning
- actuated flashers for intersection warning

Advance warning signing calls attention to unexpected conditions and to situations that might not be readily apparent to road users.

Advance intersection warning signs have the following crash reduction factors:

CRF = 30% Urban
CRF = 40% Rural

The following illustration is a curve speed warning sign. Warning signs for curves have a crash reduction factor (CRF) of 22%.

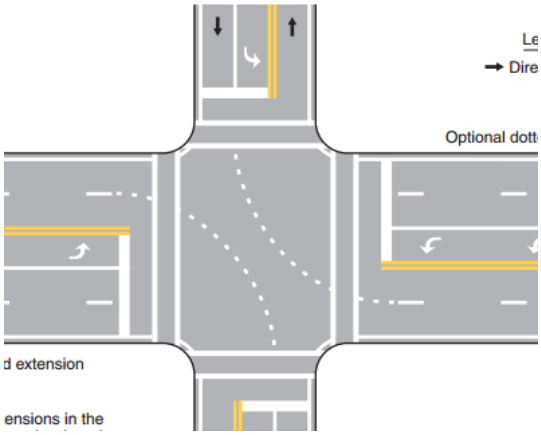
Automated Real-Time Advance Warning

This application can be used in advance of a sight restricted approach to a high speed intersection. The following illustration shows a dynamic activated flasher on a stop sign. A detector on the approach is used to activate the flasher.

F. Pavement Marking Countermeasures

Stop Bars and Placement
Dotted Line Tapers
Dashed Guide Lines for Turn Lanes

The following illustration shows the design of an intersection with 2' – 4' skip line delineating the opposing left turns.



Advance Transverse Rumble Strips

Advantages:

- Rumble strips "alert" drivers in advance of the intersections
- Rumble strips are particularly appropriate on stop-controlled approaches to rural intersections

- Up to a 50% reduction in rear-end and stop violation crashes
- Key to effectiveness is to apply sparingly so that they retain there "surprise" value in gaining driver attention

Disadvantages:

- No consensus
- Noise is a problem
- Potential loss of control for motorcycles (One possible solution is to omit 2' of the rumble bar for motorcycles.)

G. Intersection Lighting Countermeasures

Lighting has the highest benefit to cost ratio of any of the traffic safety countermeasures. The crash reduction factor (CRF) for lighting for intersections is approximately 50%.

Lighting at High Volume Signalized Intersections	
Treatment	**Finding**
Add lighting	30% reduction in all collisions. 50% reduction in nighttime collisions.
Add lighting	43% reduction in fatal crashes. 17% reduction in injury crashes.

VII. Intersection Geometrics

A. Key Safety Principles and Design

No highway is safe, only safer or less so. Highway segments with intersections represent greater "risk" than "pure" segments. Segments with intersections and other geometric features represent even greater risk. We know how to make highways safer. However, the law of diminishing marginal return applies and money should be spent effectively.

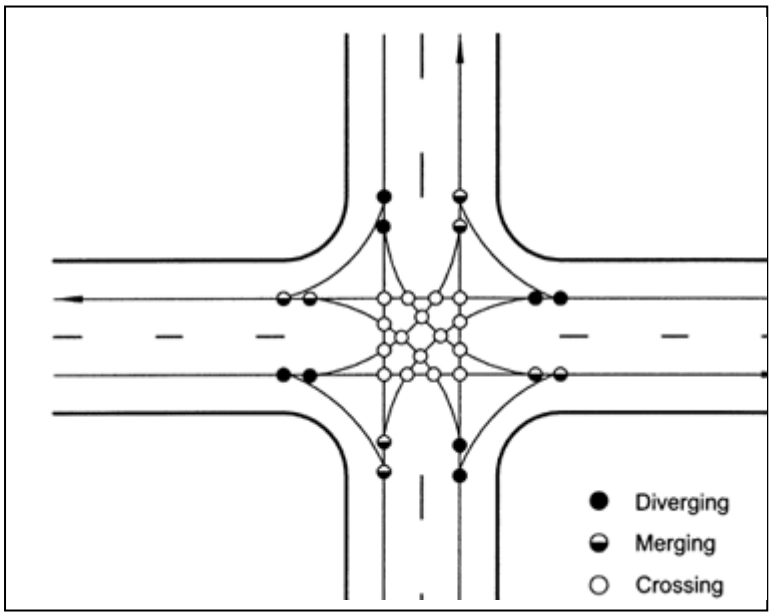
The following illustration shows a roadway segment with an on a hill with a curve approaching a signalized intersection. This intersection has a greater risk of crashes.

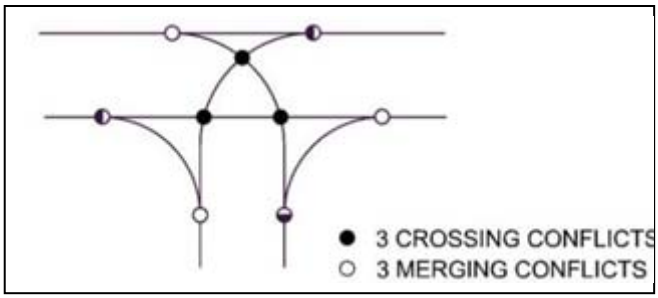
B. Geometric Features Related to Substantive Safety at Intersections

- Configuration – number of legs
- Access near intersection
- Left and right turn lanes
- Offset left turn lane geometry
- Shoulder widening
- Intersection sight distance
- Horizontal and vertical alignment
- Angle of intersection (skew)
- Splitter islands (channelization)

Configuration – Number of Legs

The 4-leg intersection provides a greater number of turning movements, but a greater number of conflict points (32 conflict points). The 3-leg intersection provides less turning movements, but fewer conflict points (9 conflict points). The following illustrations compare the number of conflict points for a 4-leg intersection vs. a T-intersection.





Access Near Intersection

Access points within 250 feet upstream or downstream of an intersection are undesirable. The connections should be consolidated into a multiple access point if possible. If possible, relocate the access to the adjacent side road.

Left and Right Turn Lanes

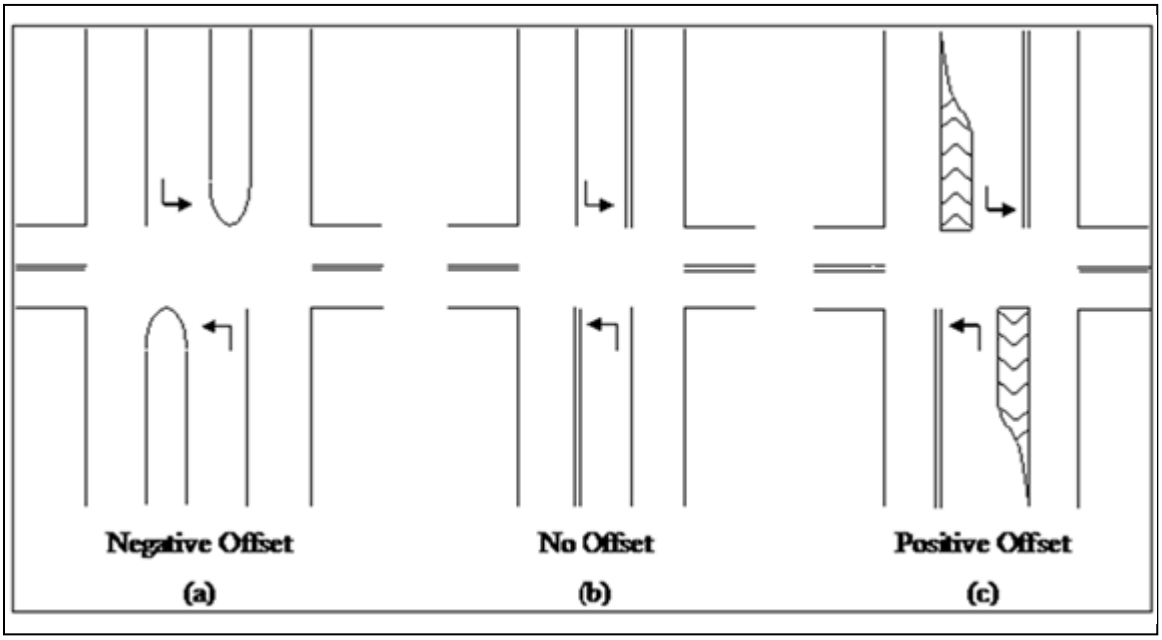
Left and right turn lanes are beneficial to the movement of mainline through traffic. Left turn lanes remove traffic from through lanes, thus:

- mitigate rear-end conflicts
- enable selection of safe gap

Offset Left-Turn Lane Geometry

Vehicles turning left from opposing left turn lanes restrict each other's sight distance unless the lanes are sufficiently offset. Offset is defined as the lateral distance between the left edge of a left turn lane and right edge of an opposing left turn. Positive offsets are desirable with a minimum 2 foot offset for a passenger car and 4 foot offset for a truck.

The following illustration shows the difference in an intersection layout with negative offset, no offset and positive offset.



A *negative offset* places the left turning vehicles in direct eyesight of each other resulting in an obstruction of the sight triangle. The left turning vehicles are unable to see oncoming through traffic.

No offset places the left turning vehicles opposing one another. The left turning vehicles are unable to see oncoming through traffic.

A *positive offset* places the left turning vehicles so that the left turning vehicle can see oncoming traffic without being blocked by the opposing left turning vehicle.

Shoulder Widening

Shoulders are beneficial by providing extra pavement for u-turns and through traffic encroachment. The crash reduction factor per foot of shoulder widening at rural intersections is 2.8%.

Intersection Sight Distance

Intersections must be designed to provide sufficient sight distance so that drivers can control and safely operate their vehicles. Sight distance is based upon speed and is an important factor in intersection design.

Horizontal and Vertical Alignment

Horizontal and vertical alignments affect the safety of an intersection. Sight distance may be an issue if an intersection is located on a horizontal or vertical curve. It is important that the engineer evaluate the location of the intersection in relation to these characteristics. If possible, the intersection should be located on a straight and flat segment.

Angle of Intersection (Skew)

The angle of the intersection affects the safety of the intersection. A 90-degree intersection is the safest. The greater the skew at an intersection, the more difficult the turning movements. Sight distance becomes an issue in turning movements.

Splitter Islands (Channelization)

Splitter islands can be used to separate turning movements at intersections. These islands can be used to place supplemental signs or post mounted signals to provide additional information for the driver.

VIII. Red Light Running

Crash data from the National Highway Traffic Safety Administration indicated that in 2002, there were 921 fatalities and 178,000 injuries resulting from 207,000 crashes attributable to motorists running red lights at signalized intersections. Crashes involving red light running are much more likely to cause an injury or a fatality than other intersection crashes. The number of fatal motor vehicle crashes at traffic signals is rising faster than any other type of fatal crash nationwide.

Red light running occurs when a driver enters an intersection after the traffic signal has turned red. The reasons that motorists run red lights are both intentional and unintentional.

The countermeasures to discourage red light running can be grouped into the following four areas:

A. Increase Signal Visibility/Conspicuity

Placement and Number of Signal Heads.
Overhead signal displays help to overcome the three most significant obstacles posed by pole-mounted signal heads, which are (1) poor conspicuity, (2) mounting locations may not provide a display with clear meaning and (3) motorists' line-of-sight blockage to the signal head due to other vehicles.

Signal for Each Approach Lane.
The MUTCD only requires a minimum of two signal faces for the major movement on the approach. Using a signal for each lane increases the likelihood the motorist will see the display.

Size of Signal Displays.
To increase signal visibility, 12-inch signal lenses should be considered for all signals.

Programmable Lens Signals.
The optically programmed or visibility-limited signals limit the field of view of a signal. The MUTCD permits the use of these signals at intersections when the driver sees the signal indications intended for other approaches before seeing the signal indications for their own approach.

Louvers.

Louvers are used to avoid confusion on intersection approaches where motorists may be able to see the signal indication for another approach, due to a skewed intersection. Louvers block the view of the signal from another approach.

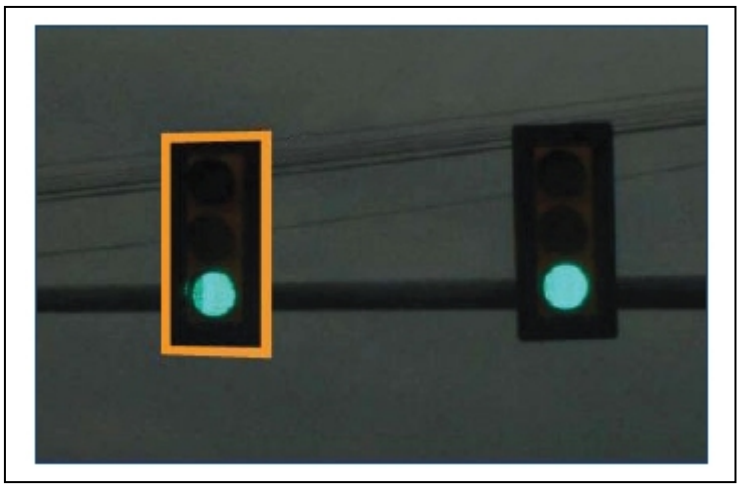
LED Signal Lenses.

LED units are used for three main reasons: they are energy efficient, brighter than incandescent bulbs and have a longer life. LED traffic signal modules have service lives of 6 to 10 years as compared to incandescent bulbs that have a life of only 12 to 15 months. Some studies have shown that LEDs loose their brightness over time. Research regarding the impacts of LED signal lenses on crash rate has not been undertaken.

Backplates.

Backplates are used to improve the signal visibility by providing a black background around the signals, thereby enhancing the contrast. They are useful for signals oriented in the east-west direction to contrast the glare effect of the rising and setting sun. A retroreflective yellow border strip surrounding the outside perimeter of sign backplates has been found to significantly reduce night-time crashes at signals.

The following illustration shows a fluorescent background on a signal head at night.



B. Increase Likelihood of Stopping

Signal Ahead Signs.
The MUTCD requires an advance traffic control warning sign where the signal is not visible from a sufficient distance to permit the driver to respond to the device.

Advance Warning Flashers.
Used to warn the driver when a traffic signal on their approach is about to change to the yellow and then red phase.

Rumble Strips.
Series of intermittent, narrow, transverse areas of rough-textured, slightly raised or depressed road surface. They provide an audible and vibro-tactile warning to the driver. They can be effective in alerting drivers of a signal with limited sight distance.

Left-Turn Signal Sign.
Provides additional information not given in the actual signal indication to the driver by specifying the control device for different intersection movements.

Pavement Surface Condition.
Poor pavement friction may not allow a vehicle to stop before the intersection. Countermeasures to improve skid resistance include asphalt mixture, pavement overlays and pavement grooving.

C. Address Intentional Violations

Signal Optimization.
Interconnected signal systems provide coordination between adjacent signals and are proven to reduce stops, reduce delays, decrease accidents, increase average travel speeds and decrease emissions. If drivers are given the best signal coordination practical, they may not be compelled to run a red light.

Signal Cycle Length.
Poor timing of signal cycle length can increase driver frustration that might result from unjustified short or long cycle lengths. The danger of red light running results from drivers not wanting to wait several minutes for the next green interval.

Yellow Change Interval.
A properly timed yellow interval is essential to reduce signal violations. The engineer should ensure that the yellow interval is adequate for the conditions at the intersection and expectations of the motorists.

All-Red Clearance Interval.
An all-red clearance interval is that portion of a traffic signal cycle where all approaches have a red signal displayed. The purpose of the all-red interval is to allow time for vehicles that entered the intersection during the yellow change interval to clear the intersection before the conflicting approach turns to green.

Dilemma Zone Protection.
Is defined as the area in which it may be difficult for a driver to decide whether to stop or proceed through an intersection at the onset of the yellow signal indication. One countermeasure is to place vehicle detectors at the dilemma zone to extend the green interval so the vehicle can travel through the intersection.

D. Eliminate Need to Stop

Unwarranted Signals. There may be a high incidence of red light running if a traffic signal is perceived as not being necessary and does not command the respect of the motoring public. Sometimes signals are installed for reasons, such as traffic volumes, that dissipate over time. The removal of a traffic signal should be based on an engineering study.

Roundabout Intersection Design. When a roundabout replaces a signalized intersection, the red light running problem is eliminated.

IX. Roundabouts

A roundabout is a one-way circular intersection without traffic signals in which traffic flows around a center island. Roundabouts feature yield control for all entering traffic, channelized approaches and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 30 mph.

Roundabouts are alternatives to conventional intersections. Roundabouts have been proven safe and effective in the rural environment.

- Number of conflicts is reduced
- Severe conflicts (angle) are eliminated
- Speed differentials are reduced or eliminated

A. Roundabout Safety

Research indicates that well designed roundabouts can be safer and more efficient than conventional intersections. Safety benefits of roundabouts include:

- Fewer conflict points in comparison to conventional intersections; fewer hazardous conflicts, such as right-angle and left-turn head-on crashes
- Low speeds allow drivers more time to react to potential conflicts
- Low relative speeds limit crash severity
- Fewer annual injury crashes than rural two-way stop controlled intersections
- Fewer injury accidents per year than signalized intersections

B. Issues to Review when Considering Roundabout Design Alternatives

- Space feasibility
- Physical or geometric complications such as right-of-way limitations, utility conflicts or drainage problems
- Proximity of generators of significant traffic that might have difficulty negotiating the roundabout, such as oversized trucks
- Proximity of traffic control devices that would require pre-emption, such as railroad tracks or drawbridges
- Traffic congestion that would cause routine back-ups into the roundabout, such as over capacity signals.
- Intersection of a major arterial and a minor arterial or local road where an unacceptable delay to the major road could be created.
- Heavy pedestrian or bicycle movements in conflict with high traffic volumes.
- Coordinated signal system

X. Older Drivers at Intersections

Driving within intersection environments requires complex speed-distance judgments under time constraints. This scenario for intersection operations can be more problematic for older drivers. According to the National Highway Traffic Safety Administration, older drivers are more likely than drivers in their 30s, 40s, or 50s to be involved in traffic crashes, and they are more likely to be killed in traffic crashes. The number of Americans 65 years and older is expected to double between 2000 and 2030. Americans are living and driving longer. Together these trends suggest that the number of older drivers killed on U.S. highways will grow.

A. Solutions to Make Intersections Safer for Older Drivers

1. Design

- Use a minimum receiving lane width of 12 feet accompanied by a 4 foot shoulder.
- Use positive offset of opposing left-turn lanes.
- Design intersecting roadways to meet at a 90 degree angle.
- Provide raised channelization for left and right turn lane treatments.

2. Signs

- Install larger regulatory and warning signs.
- Use signs fabricated with high intensity retroreflective sheeting.
- Use advance street name signing for redundancy.
- Increase sign lettering size.
- At intersections, place lane use control signs on signal mast arm or span wire.

3. Pavement Markings

- Treat the median and island curb-sides with retro-reflectorized markings.
- Use retroreflective raised pavement markings.
- Use transverse pavement striping or rumble strips upstream of stop-controlled intersections where there may be sign restrictions.
- Use lane use arrows in advance of signalized intersections.

4. Traffic Signal Operations

- Where a crash pattern has occurred, eliminate permitted left turn and use protected-only left turns.

- Use a separate signal face to control turning phase versus through movement.
- Use red left arrows instead of a circular red indication at left turn signals.
- Use the formulas in the ITE 'Traffic Engineering Handbook' to calculate yellow change interval and all-red clearance based upon age differences.
- Assume slower walking speeds for signal clearance timing.

5. Traffic Signal Hardware

- Install larger (12 inch) signal lenses.
- Use backplates on traffic signals on all roads with operating speeds of 40 mph or more.
- Install additional signal heads.
- Use post-mounted signals to accommodate left-turn drivers.

XI. Road Safety Audits (RSA)

Every year, municipalities spend a considerable amount of resources on trying to reduce crashes by reconstructing and improving the roads. These activities are reactive.

An active approach is called a roadway safety audit (RSA). New roads must incorporate design and operational safety elements from the start. Roadway safety in new projects can be improved by having independent road safety specialists systematically examine and comment on the projects, while they still only exist on paper.

Road safety audits are in essence, crash prevention. The purpose is to make new roads as safe as possible before the projects are implemented. RSAs require an independent and systematic formal procedure for assessing or checking the crash potential and safety performance of a new road project or existing roads. Safety should be considered throughout the entire project from planning and development, to construction, operations and maintenance.

RSAs are a proactive low-cost approach to improving safety.

XII. Summary

National intersection safety statistics were provided to prove that safe intersection design is important. The link between standards and safety was shown by comparing nominal safety (design standards) to substantive safety (actual measured factors). Human factors as they relate to intersection safety were discussed.

Prediction of safety at intersections was discussed and a crash rate for an intersection was provided. Equations for crash frequency models for stop control of minor intersections were also provided.

Screening techniques and intersection countermeasures for intersection planning and design were provided. Roadway geometrics as they relate to intersection design were discussed. Red light running was discussed and ideas to increase the likelihood of stopping were provided.

Finally, solutions to make intersections safer for older drivers was discussed.

This course should assist an engineer in the planning and design of safer intersections.