Fatal Crashes by Junction Type

**EXHIBIT 11B-1**
Fatal Crashes by Relationship to Junction

Source: 2002 FARS data. "Other" includes crashes categorized in FARS as related to railroad grade crossings, crossovers, and unknown.

- Roadway: 72%
- Interchange or Ramp: 3%
- Driveway: 1%
- Other: 1%
- Intersections: 23%
Manner of Collision

EXHIBIT III-2
Manner of Collision for Fatal Crashes at Signalized Intersections
Source: 2002 FARS data. "Other" includes crashes categorized in FARS as sideswipe same direction, sideswipe opposite direction, other, and unknown.

Comparison of Severity

EXHIBIT III-3
Comparison of Severity Distribution of Crashes
Objectives

- Reduce frequency and severity of intersection conflicts through control and operational improvements
- Reduce frequency and severity of intersection conflicts through geometric design
- Improve sight distance at signalized intersections
- Improve driver awareness of intersections and signal control
- Improve compliance with traffic control devices
Objective I
Reduce frequency and severity of intersection conflicts through traffic control and operations

Strategy A – Employ Multiphase Signal Operations
- Two-phase signals require “unprotected” (permitted) left-turns
- Left-turns are highest risk movement, 70-75% intersection accidents are left-turn related
- Protected left-turn phases improve safety dramatically
Phasing for Safety

- Split phase may also be used to improve safety
- Not effective for operations and capacity
Problematic Left-Turn Conflicts

• Opposing through traffic
• Through traffic in same direction crossing vehicular and pedestrian traffic

Website on Signal Phasing

• http://www.webs1.uidaho.edu/niattproject/
• http://www.dot.state.mn.us/metro/trafficing/dsg_crse/chap21.html#_toc429824696
Options for Left-Turn Phasing

- Permitted
- Protected only
- Protected/permitted
  - Both lead and lag

Protected / Permitted Phasing

- Compromise between fully protected and permitted-only phasing
- Advantages
  - Reduction in delay for waiting left-turns
  - Less time needed for protected left-turns, thus more time for high priority movements
- Safety performance of protected/permitted left-turn phasing is not as good as protected only
- Dual or triple left-turn lanes should only operate with protected turn phases
Phasing for Safety

• For safety
  – Protected-only is best option
  – Guidance for selection of left-turn phasing is in NCHRP Synthesis 225: Left-Turn Treatments at Intersections,” TRB 1996

Lead versus Lag Left-Turn Phases

• Lead protected left-turn phase with green arrow minimizes conflict with through and left-turn vehicles
• Lagging left-turn phase allows some clearing of the queue in permitted portion of the cycle, then less lag green time
Safety of Lead / Lag

- Kentucky study shows lag option with higher crash experience
  - Lag: 2.07 crashes per 1000 left-turning and opposing vehicles
  - Lead: 1.27 crashes per 1000 left-turning and opposing vehicles

Safety of Left-Turn Bays with Left-Turn Phase

- California study reported;
  - 35% reduction in total accidents when left-turn lanes were added and left-turn phases used
  - 15% reduction in total accidents when left-turn lanes were added without a separate turn phase
Strategy B – Split Phases

• May be used at intersections that;
  – Are skewed
  – Have a large deflection angle for through movement
  – Have wide medians
  – Are too small for simultaneous left-turns
  – Have left and through movements sharing a lane
  – Have major imbalance in opposing left-turn volumes
  – Have different profiles or divided highway
Strategy C
Optimize Clearance Intervals

- Clearance interval defined:
  - The portion of the signal cycle between end of green phase and beginning of next green phase
  - To establish clearance intervals that meet pedestrian needs
    - Includes yellow time and all-red time
Short Clearance Intervals

- Short clearance intervals contribute to
  - Rear-end crashes
  - Right-angle crashes from signal violations
  - Extremely short clearance intervals force drivers to violate the red phase

- Detailed discussion on yellow and all-red intervals;
    http://www.ite.org/library/redlight/makingint_safer.pdf

ITE Traffic Engineering Handbook

- Yellow change time (sec) = speed (mph)/10
- Red clearance interval = 1 or 2 sec
  - MUTCD – yellow change interval should be 3-6 sec.
  - ITE Traffic Engineering Handbook – yellow change interval of 5 sec, maximum
  - Typical red clearance interval , 2 sec. Typical, 6 sec maximum
Uniform Clearance Interval Length

- Various studies suggest;
  - A uniform value of 4-5 sec. for yellow change interval length throughout a jurisdiction
  - Driver expectancy would anticipate uniform clearance intervals for a jurisdiction

ITE Handbook Clearance Interval Calculation

\[ CP = t + \frac{V}{2a \pm 64.4g} + \frac{W + L}{V} \]

where
- \( CP \) = non-dilemma change period (change + clearance intervals)
- \( t \) = perception/reaction time (nominally 1 sec.)
- \( V \) = approach speed (ft/sec or 1.47 x mph)
- \( g \) = percent grade (+upgrade, -downgrade)
- \( a \) = deceleration rate (ft/sec\(^2\) – typical 10 ft/sec\(^2\))
- \( w \) = width of intersection, curb to curb (ft)
- \( L \) = length of vehicle (ft – typical 20 ft)

*Also metric – m, m/sec, and m/sec\(^2\)
Lengthening Clearance Intervals

• Clearance intervals are ‘lost’ time in the cycle
• Longer clearance times may require longer cycles to offset lost time
• Longer clearance times and longer cycles lead to red light running

Strategy D – Restrict or Eliminate Turning Maneuvers
(including Right-Turns on Red, RTOR)

• Where channelization or signal retiming are difficult: Implement to reduce crashes or risky maneuvers;
  – Restrict or eliminate turning maneuvers by channelization
  – Prohibit right-turns on red
Restrict or Eliminate Turning Maneuvers

- Implemented by channelization or signing;
  - Raised concrete channelization
  - Flexible delineators
  - Signing requires periodic enforcement

Prohibit Right-Turns on Red

- RTOR prohibition can reduce crashes and their severity due to
  - Limited sight distance
  - Pedestrian interaction
  - Vehicles from the left and left-turns from cross streets
  - RTOR prohibition can be time dependent
  - Effective signing is critical
Strategy E
Coordinate Signal Timing

- Signal coordination improves quality of operation and safety
  - Vehicle platooning reduces number and frequency of stops and maintains uniform speeds
    - Reduces rear-end conflicts
    - Eliminates problems of locating gaps for left-turns
- Signal coordination
  - Reduces red light running
  - Arizona study showed 6.7% decrease in crashes

Strategy F
Employ Emergency Vehicle Preemption

- Signal preemption allows emergency vehicles to proceed through intersections
  - More quickly; More safely
- Emergency response time is reduced by 14-50% (Callura, et al., 2001)
- Study showed 70% reduction in crashes with emergency vehicles
**Strategy G – Improve Operation of Pedestrian and Bicycle Facility at Signalized Intersections**

- About 1/3 of pedestrian-related crashes are within 50 ft. of an intersection. Of these;
  - 30% involve turning vehicles
  - 22% involve pedestrian running across intersection or out in front of vehicle
  - 16% driver error

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**Traffic Control Improvements to Increase Pedestrian Safety, include**

- Pedestrian signs, signals and markings
- Crossing guards for school children
- Lighted school zone crosswalks
- Pedestrian-only or pedestrian-lead phase
- Prohibition of RTOR
- Information signs on ped push buttons
- Push button functioning indicator
Strategy G
Remove Un warranted Signals

• Changed conditions may no longer warrant traffic signal, e.g., decreased volume
• Un warranted signals cause;
  – Excessive delays
  – Rerouting traffic to other roads and intersections
  – Higher crash rates
  – Violation of traffic signal control
• Safety of removal of unwarranted signals
  – Converted to all-way stop control – accidents decreased by one/year
  – Converted to two-way stop control – right angle crashes increased while rear-end crashes decreased some amount
Objective II

Reduce frequency and severity of intersection conflicts with geometrics

Strategy H – Provide/Improve Left-Turn Channelization Options

- Provide left-turn lanes
- Lengthen left-turn lanes
- Provide off-set for left-turn lanes
- Provide positive guidance with channelization
- Delineate turn path
Strategy I
Install Left-Turn Lane

- Remove left-turns from through movement
- Shadows and provides refuge for left-turns

- See also Appendix 6, Volume 12
- http://safety.transportation.org/
### EXHIBIT U-12A
Recommended Accident Modification Factors for Installation of Left-Turn Lanes on the Major-Road Approaches to Rural Intersections

<table>
<thead>
<tr>
<th>Intersection Type</th>
<th>Intersection Traffic Control</th>
<th>Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>One Approach</td>
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<tr>
<td>Three-leg</td>
<td>Stop sign*</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>Traffic signal</td>
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<td>Four-leg</td>
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<td></td>
<td>Traffic signal</td>
<td>0.82</td>
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* On minor-road approach(es).

### EXHIBIT U-12B
Recommended Accident Modification Factors for Installation of Left-Turn Lanes on the Major-Road Approaches to Urban Intersections

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<thead>
<tr>
<th>Intersection Type</th>
<th>Intersection Traffic Control</th>
<th>Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>One Approach</td>
</tr>
<tr>
<td>Three-leg</td>
<td>Stop sign*</td>
<td>0.67</td>
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<tr>
<td></td>
<td>Traffic signal</td>
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<tr>
<td></td>
<td>Traffic signal</td>
<td>0.90</td>
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</tbody>
</table>

* On minor-road approach(es).
Lengthening Left-Turn Lane

- Left-turn lane design should allow vehicles to slow out of the through traffic stream

Provide Positive Offset for Left-Turn Lanes

- Left-turning vehicles must have adequate sight distance to approaching vehicles
- Medians of 18 ft. or more require positive offset for sight distance
Delineate Turn Path

- Especially helpful with multiple left-turn lanes and with simultaneous opposing left-turns

![Delineation of Turn Paths for Double Left-Turn Lanes](Image)

Source: Federal Highway Administration, In press.

Strategy J – Provide or Improve Right-Turn Channelization

- Provide right-turn lane
  - Effective to reduce rear-end conflicts on high-volume high-speed roadways
### EXHIBIT V-13
Recommended Accident Modification Factors for Installation of Right-Turn Lanes on the Major-Road Approaches to Rural and Urban Intersections

<table>
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<tr>
<th>Intersection Traffic Control</th>
<th>Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed</th>
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<td>One Approach</td>
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<tr>
<td>Stop sign*</td>
<td>0.86</td>
</tr>
<tr>
<td>Traffic signal</td>
<td>0.96</td>
</tr>
</tbody>
</table>

*a On minor-road approach(es).*
Lengthening Right-Turn Lanes

- Right-turn lane should be long enough to
  - Allow for deceleration plus storage in the lane
  - Appropriate taper lengths, not excessively long
Strategy K - Improve Geometrics of Pedestrian Facilities

- Potential low-cost pedestrian safety improvements
- Continuous sidewalks
- Signal and marked crosswalks
- Sidewalk setbacks
- Median refuge areas
- Pedestrian overpasses
- Intersection lighting
- Relocate transit stops to far side
- Traffic calming options to reduce vehicle speeds and volume
Strategy L – Improve Geometrics of Bicycle Facilities

- Problems to bicyclist safety are high vehicle speeds and traffic volumes
- Potential improvements include:
  - Widen outside through lanes
  - Add bike lanes
  - Provide independent crossing structures
  - Provide median refuge areas
  - Upgrade storm strain grates to bicycle-sale design
  - Implement lighting
Strategy M – Revise Geometry of Complex Intersections

• Potential options include:
  – Convert 4-leg to two T-intersections
    • For very low volume on cross street; reduces number of crossing conflicts
  – Convert two T-intersections to one 4-leg intersection
    • With very high volumes on the cross street, safety is improved with a single intersection
    • Left-turning accidents will be reduced

Improve Intersection Skew Angle

• Large skew angle
  – Increases the distance to travel through intersections
  – More difficult to judge gaps with RTOR
  – Crossing distances for pedestrians are increased
Remove Deflection in Through-Vehicle Paths

- Maximum deflection angles should be 3-5°
- Forced path changes for through-vehicles violate driver expectations
- Crashes likely to include;
  - Rear end, side swipe, head-on, and angle
- Pavement markings are reasonable solution

Close Intersection Legs

- Would eliminate accidents for vehicles from that leg
- Effectiveness is site specific
Strategy N – Construct Special Solutions

- Provide indirect left-turns
- Reconstruct intersections, convert to roundabouts
- Convert 2-way street to 1-way pair
- Construct interchange

Indirect Left-Turn Alternatives

- Remove left-turns from high volumes intersections, therefore reduced accidents
EXHIBIT V-17
Median U-Turn Crossover
Source: Federal Highway Administration, in press.

EXHIBIT V-18
Super Street Median Crossover
Source: Federal Highway Administration, in press.
EXHIBIT 7-19
Quadrant Roadway Intersection
Source: Federal Highway Administration, In press.

EXHIBIT 7-20
Split Intersection
Source: Federal Highway Administration, In press.
Convert to Roundabout

- Roundabouts have proven to be safer;
  - Than 20,000 veh/day signalized intersection, crash rate 33% lower in urban/suburban, and 56% lower in rural
  - Than 40,000 veh/day signalized intersection, crash rate 15% lower
  - At 50,000 ADT roundabouts and signalized intersections are comparable

Source: Roundabouts: An Informational Guide
http://www.tfhrc.gov/safety/00-0671.pdf
Convert 2-Way Street to 1-Way Pair

• Improve safety by;
  – Reducing number of conflicts at intersections
  – Allowing unopposed turn maneuvers
  – Simplifying operations and signal phasing at multi-leg intersections
  – Allowing fewer conflicts for pedestrians
  – Providing more gaps for vehicles and pedestrians at unsignalized crossings

• Safety effectiveness
  – 10-50% reduction in total crashes

• Operational improvement
  – 50% increase in capacity for the two streets
Construct Interchange or Grade Separation

- Expensive solution
- Usually, employed for operational or capacity improvement

Objective III

Improve sight distance at signalized intersections
Strategy O
Clear Sight Triangles

- Restore sight distance by removing vegetation, roadside appurtenances, buildings and other objects
- Sight restrictions on private property are difficult to remove

Redesign Intersection Approaches

- Possible alternatives include;
  - Realigning minor-road approaches to intersect at different locations or angle
  - Close an intersection leg
  - Eliminate intersection skew
  - Eliminate off-set through lanes with more than 50% off-set
Objective IV

Improve driver awareness of intersections and signal control

- Critical to intersection safety
- Important to perceive intersection layout
- Vital to perceive intersection control
- Locating back of queue is critical
Strategy P – Improve Visibility of Intersection Approaches

- Improve signing and delineation
- Install large signs
- Provide intersection lighting
- Install rumble strips on approaches
- Install queue detection system

Improve Signing and Delineation

- Aim is to prepare drivers for intersection ahead
- May use;
  - advance guide signs
  - advance warning signs
  - warning signs
  - pavement markings
  - overhead street signing
  - post-mounted delineators
Advance Warning Helpful

- Particularly helpful to elderly drivers

EXHIBIT V:23
Advanced Warning Sign for Red Signal
Source: Federal Highway Administration, in press.

Install Larger Signs

- Sign visibility improved with larger signs
- Ability to read legend is improved
- Aids seeing by older driver
Provide Intersection Lighting

- Assists driver awareness
- Older drivers need more light to ‘see’
- Crash data has shown any added lighting increases safety

Install Rumble Strips on Approaches

- Particularly appropriate where crashes are due to lack of recognition of signalized intersections
- Typically used where other approaches, such as, ‘signal ahead’, have not worked
Install Queue Detection System

- Queue detection system identifies the presence of vehicles
- ODOT implemented system in rural location with unexpected long seasonal queues
- Safety Applications of ITS in Rural Areas, FWHA

Strategy Q – Improve Visibility of Intersection Signals and Signs

- Options
  - Install additional signal heads
  - Provide visors to shade lenses from sunlight
  - Use programmed signal lenses
  - Install back plates
  - Install larger 12-in. signal lenses
  - Remove or relocate unnecessary signs
  - Provide far-side left-turn signal
Objective V

Improve driver compliance with traffic control devices

Strategy R – Provide Public Information and Education

• Provide targeted public information and education campaign

• Possible media;
  – Television, ads, spots, interviews,
  – Radio, ads, spots, interviews
  – Flyers, posters
  – Driver education classes
Strategy S – Provide Targeted Conventional Enforcement of Traffic Lane

- Three “E’s” of highway safety
  - Education
  - Engineering
  - Enforcement
- Enforcement agencies often select locations for targeted enforcement based on crash, citation and other sources
- OTSD, ODOT often helps fund such efforts

Strategy T – Implement Automated Enforcement of Red-Light Running

- Red light running is a growing traffic safety problem
- Automated enforcement uses photo radar and video camera systems
- Camera should turn on after signal turns red
  - Detector senses approaching vehicle and sends signal to camera
  - Camera photographs vehicle as they enter the intersection
  - A grace 1-sec. grace period is recommended so drivers caught in dilemma zone are not photographed
  - Two other cities, 34% decrease
    - Reductions in violations, 44% (Fairfax, VA)
    - Oxnard, CA – 41% reduction
    - ITE Report – 23-83% decrease
Strategy U – Implement Automated Approach Speeds Enforcement

- Automated enforcement effectiveness
  - Paradise Valley, CA – 40% decrease in crashes
  - National City, CA – 51% decrease in crashes
- Speed reductions at 25 mph experimental site
  - Photo radar, reduced excessive speeds, 30.2%
  - Speed display board, reduced 34.9%
  - Enforced display board, reduced 31.8%
Strategy V
Control Speed on Approaches

- Lowering speeds on approaches reduces crash severity
- Techniques to control speeds
  - Geometric design
  - Signal control technology
  - Traffic calming treatments

Design to Control Speed

- Turn the roadway
  - Add horizontal curvature to control speeds
  - Raised intersection
    - Slows vehicles due to its uniqueness
- Funnel the traffic
  - Narrow the roadway as it enters the intersection
Objective VI

Improve access management near signalized intersection

Strategy W – Restrict Access to Properties Near Intersection

- Control driveways within functional area of an intersection
  - Eliminate access movements
  - Access conflicts yield rear end and angle crashes
  - Speed changes occur near intersections
Functional Area of Intersection

- Functional area of intersection
  - Defined by approach and departure functional distances

![Diagram of Functional Area of Intersection]
Strategy X
Restrict Cross-Median Access

- Access near intersection creates conflicts near the intersection
- Drivers do not expect median crossings to accesses near intersection
- Accidents occur between median crossing vehicles and through vehicles
Objective VII

Other treatments to improve safety

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Strategy Y – Improve Surface Drainage
in Intersection and on Approaches

- Drainage problems can result from surface water
- Ponding or deep flow can cause lost control from viscous damping
- Thin sheets of water can result in hydroplaning
Strategy Z- Provide Skid Resistant Pavements in Intersections and on Approaches

• Skid resistance is influenced by
  – Vehicle speed
  – Vehicle tire condition
  – Surface condition

• Surface skid resistance is function of
  – Macro-texture
    • Mechanical interlock between the tread and coarse aggregate
  – Micro-texture
    • Chemical bonding, fine scale grittiness, aggregate surface texture

Strategy AA – Relocate Signal Hardware out of Clear Zone

• Move traffic signal supports and control cabinets as far as possible from pavement edge
• Locate behind a roadside barrier if one exists
### Strategy BB – Restrict or Eliminate Parking on Intersection Approach

- Parking adjacent to turning and/or through lanes create operational conflicts
- Parked vehicles present roadside obstacles
- Parked vehicles block the sight triangle of stopped vehicles

### Restrict or Eliminate Parking on Intersection Approaches

- Crash experience
  - 20% of non-freeway crashes are parking related
  - Mid-block crash rates could be expected to decrease 75%
  - Australia banned parking on intersection approaches, reduced crashes 10%