Traffic Safety Fundamentals Handbook

Minnesota Department of Transportation
Office of Traffic, Safety and Technology

Revised June 2015
Prepared by CH2M, Inc.

MnDOT Traffic Safety Fundamentals Handbook – Introduction

The Minnesota Department of Transportation (MnDOT) published the original version of the *Traffic Safety Fundamentals Handbook* in 2001 and an updated version in 2008. Over 3,500 copies have since been distributed through MnDOT's education and outreach efforts to practicing professionals in both government agencies and the private sector. In addition, the Handbook has been used as a resource in undergraduate and graduate traffic engineering classes at the University of Minnesota and is available to professionals in other states through the online posting on MnDOT's website.

In the years since 2001, the field of traffic safety has witnessed a number of important changes. First, federal legislation (SAFETEA-LU) raised the level of importance of highway safety by making it a separate and distinct program and by increasing the level of funding dedicated to safety. In response to this legislation, the Federal Highway Administration (FHWA) provided implementation guidelines that required the states to prepare Strategic Highway Safety Plans (SHSPs) and encouraged their safety investments to be focused on low-cost stand-alone projects that can be proactively deployed across both state and local highway systems.

MnDOT initially prepared a Comprehensive Highway Safety Plan in 2004 and then completed updated Strategic Highway Safety Plans in 2007 and 2014. These documents included identification of a statewide safety goal, safety focus areas, and lists of high-priority safety strategies. These Plans also included key commitments intended to address FHWA's safety objectives – adopting a long-term goal of achieving no traffic-related fatalities, a focus on reducing the most serious crashes, adding a new approach to the safety project development process that uses the results of systemic risk assessments to identify candidates for safety investment (in addition to the traditional site assessment approach used at high crash locations), dedicating a fraction of Highway Safety Improvement Program (HSIP) funds to improvements on local roadway systems, and increasing the level of engagement of local agencies in the statewide safety planning process. The key outcomes of these commitments include revising the priorities for HSIP, directing approximately 50% of HSIP funds toward implementing safety projects on the State's local system of roadways, and completion of a project that was a first of its kind – the County Roadway Safety Plans (CRSPs). This project involved MnDOT providing

the technical assistance necessary to complete systemwide risk assessments and individual Safety Plans for each of Minnesota's 87 counties. The county plans identified the priority crash types, a short list of effective, low-cost safety strategies, and the identification of the high-priority locations for HSIP investment. The CRSP project identified more than 17,000 safety projects, with an estimated implementation cost of approximately $246M.

As a result of these strategic safety planning efforts and the hard work of safety professionals in both state and local highway agencies, hundreds of highly effective safety projects have been implemented, and the results are impressive – Minnesota met the initial goal of achieving under 500 fatalities by 2008, and by 2011 the number fell to fewer than 400 fatalities. However, one fact remains constant – highway traffic fatalities are still the leading cause of death for Minnesotans under 35 years of age. This suggests there is still much work to do in order to move Minnesota Toward Zero Deaths.

This new edition of the Handbook has been updated to reflect new safety practices, policies, and research and is divided into four sections:

- **Crash Characteristics** – national and state crash totals, including the basic characteristics as a function of roadway classification, intersection control, roadway design, and access density.
- **Safety Improvement Process** – Site Analysis at High Crash Locations + Systemic Analysis = Comprehensive Safety Improvement Process.
- **Traffic Safety Toolbox** – identification of new tools (Highway Safety Manual and Crash Modification Clearinghouse) and an update on strategies, with an emphasis on effectiveness.
- **Lessons Learned**

For additional information regarding traffic safety, please contact either MnDOT's Office of Traffic, Safety and Technology, State Traffic Safety Engineer (651) 234-7011 or Division of State Aid, State Aid Program Support Engineer (651) 366-3839.

Document Information and Disclaimer

Prepared by: CH2M, Inc.

Authors: Howard Preston, PE, Veronica Richfield, and Nicole Farrington, PE

Funding: Provided by MnDOT Division of State Aid for Local Transportation

Published by: MnDOT Office of Traffic, Safety and Technology

The contents of this handbook reflect the views of the authors who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the views of policies of the Minnesota Department of Transportation at the time of the publication. This handbook does not constitute a standard, specification or regulation.

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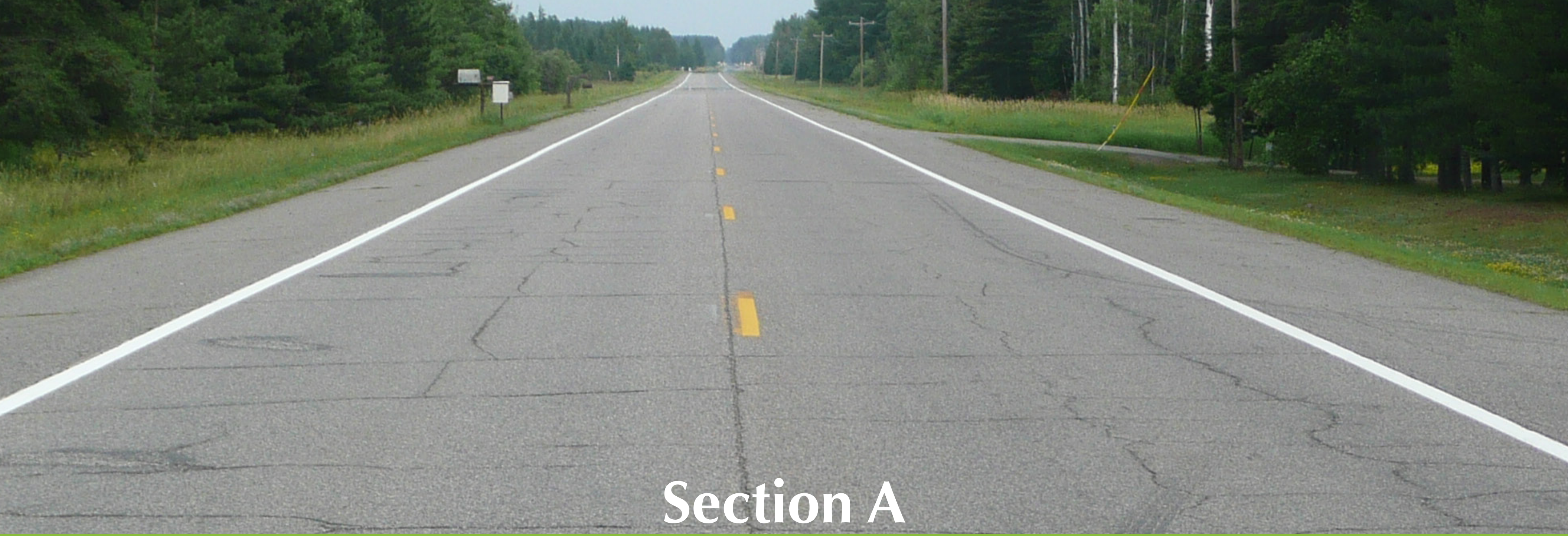


Section A
Crash Characteristics

Nationwide Historical Crash Trends

	1972	1979	1989	1999	2004	2007	2009	2012	2013
Crashes									
Total (thousand)	N/A	N/A	6,700	6,300	6,181	6,024	5,505	5,615	5,687
Fatal (thousand)	N/A	N/A	41	37	38	37	31	31	30
Injury (thousand)	N/A	N/A	2,153	2,026	1,862	1,711	1,517	1,634	1,591
PDO (thousand)	N/A	N/A	4,459	4,226	4,281	4,275	3,957	3,950	4,066
Fatalities									
Total	54,589*	51,093	45,582	41,717	42,836	41,259	33,883	33,561	32,719
Traffic									
Registered Vehicles (million)	122	144	181	213	238	257	259	266	N/A
VMT (trillion)	1.3	1.5	2.1	2.7	3.0	3.0	3.0	3.0	3.0
Rates									
Crashes/100 MVM	N/A	N/A	317	235	206	199	186	189	192
Fatalities/100 MVM	4.3	3.3	2.2	1.5	1.4	1.4	1.1	1.1	1.1
Fatalities per million registered vehicles	458	355	252	195	180	161	131	126	N/A

*1972 was the worst year for fatalities in U.S.

N/A Not Available
PDO Property Damage Only
VMT Vehicle Miles Traveled
100 MVM 100 Million Vehicle Miles

National Highway Traffic Safety Administration (NHTSA)

Highlights

- Nationally, over the past 10 years there have been almost 55 million crashes. Over that same time period, the number of fatalities has approximately decreased from 42,000 to 32,000 annually.
- Over the 10-year period, exposure (VMT) has increased only slightly and has been almost flat during the past 5 years.
- The long-term trend is fewer crashes and fatalities and a relatively flat level of exposure.
- The dramatic decrease in the number of traffic fatalities – 24% over the 10-year period brings the annual number of deaths (32,719) to a level that is lower than any time in the previous 60 years.
- The combination of decreasing fatalities and a flat exposure results in a fatality rate of 1.1, which is a 21% reduction and the lowest fatality rate ever.

Upper Midwest Area 2013 Crash Data

	Minnesota	North Dakota	South Dakota	Iowa	Wisconsin
Crashes					
Total	77,707	18,977	16,620	49,798	118,254
Fatal	357	133	121	290	491
Injury	21,960	3,901	3,921	13,091	28,747
PDO	55,390	14,943	12,578	36,417	89,016
Fatalities					
Total	387	148	135	317	527
Traffic					
Registered Vehicles (million)	5.1	0.8	1.0	4.3	5.7
VMT (billion)	57.0	10.1	9.1	31.5	59.5
Rates					
Crashes/MVM	1.4	1.9	1.8	1.6	2.0
Fatalities/100 MVM	0.7	1.5	1.5	1.0	0.9
Fatalities/MRV	76	184	134	75	93
Costs					
US Dollars (million)*	$6,765	$2,063	$2,050	$4,853	$10,149

* Estimated based on distribution of injuries and using MnDOT 2013 crash costs.

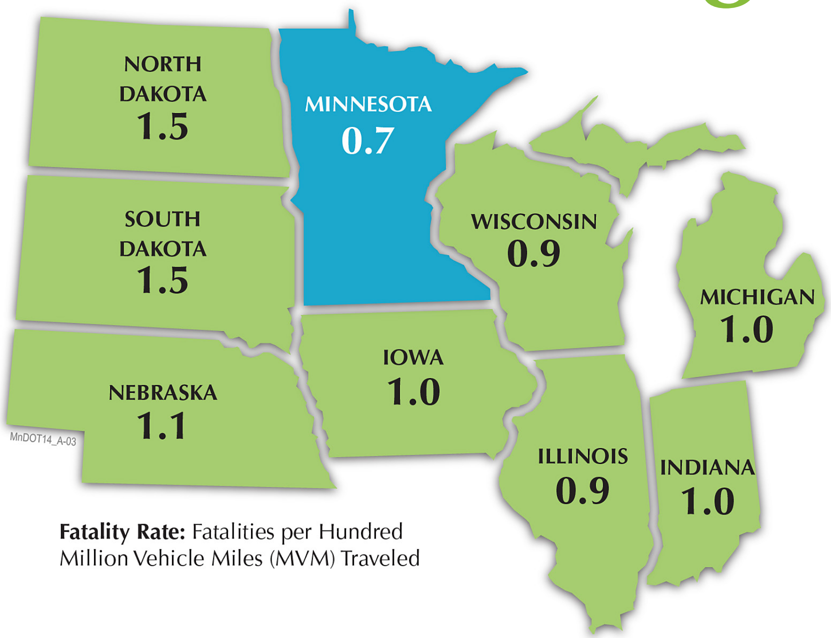
PDO Property Damage Only
VMT Vehicle Miles Traveled
MRV Million Registered Vehicles
100 MVM 100 Million Vehicle Miles

2013 Publications of MnDOT, NDDOT, SDDOT and IowaDOT
WisDOT data is preliminary

Highlights

- Regionally, there is a wide variation from state to state in both the total number of crashes (16,000 to 120,000) and the number of fatalities (121 to 491).
- Minnesota has averaged approximately 75,000 crashes and has recorded between 357 and 455 fatalities annually since 2008.
- The trend in Minnesota is fewer crashes and fatalities, in spite of an increase in exposure (VMT).
- Minnesota has been a leader in the area of highway safety, with one of the lowest statewide average crash and fatality rates compared to other states in both the region and the nation.
- There is a relationship between the number of fatal crashes and fatalities. In general across the upper midwest area, the ratio was 1.1 fatalities per fatal crash.

Fatality Rates of Surrounding States–2013



Fatality Rate: Fatalities per Hundred Million Vehicle Miles (MVM) Traveled

	Minnesota		Nationally
Year	**Fatalities**	**Fatality Rate**	**Fatality Rate**
1975	754	2.9	3.4
1985	608	1.9	2.5
1995	597	1.4	1.7
2000	625	1.2	1.5
2005	559	1.0	1.5
2010	411	1.0	1.1
2012	395	0.7	1.1
2013	387	0.7	1.1

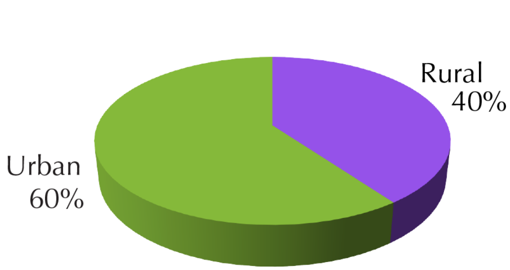
National Highway Traffic Safety Administration (NHTSA)

Highlights

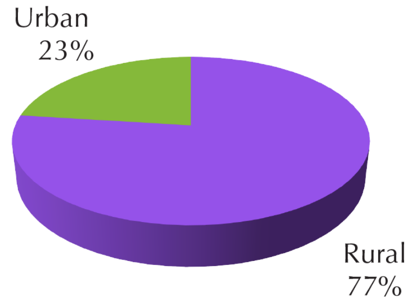
- Minnesota has the lowest fatality rate in the region and consistently one of the lowest fatality rates in the nation.
- National Fatality Rates
  - The national average is 1.1 for 2013 (2012 disaggregated rates were 1.9 on rural roadways and 0.8 on urban roadways)
  - Trends:
    - Lowest fatality rates in the northeast (mostly urban)
    - Individual state fatality rates ranged from 0.6 in Massachusetts to 1.9 in Montana
- Minnesota's overall fatality rate is 0.7 (1.1 on rural roadways and 0.4 on urban roadways).
- Nationwide, Minnesota had the second lowest fatality rate. Massachusetts has the lowest fatality rate of 0.6.
- Since 1975, Minnesota's fatality rate has dropped by almost 77%. This drop is the largest decline of any state.
- Traffic fatalities are still the leading cause of death for Minnesota residents under 35 years of age.
- The data suggest there are significant opportunities to move Toward Zero Deaths by focusing state safety efforts on the primary factors associated with severe crashes – inattention, alcohol, speeding, road edges, and intersections.

Minnesota Urban vs. Rural Crash Comparison

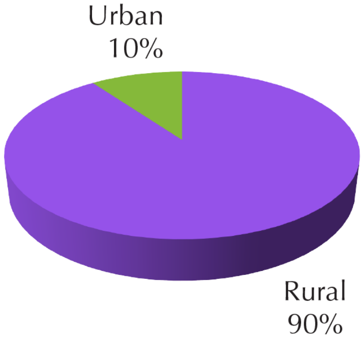
Total Crashes



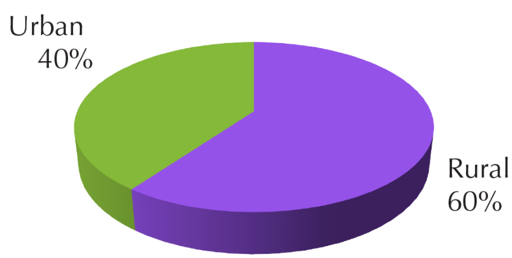
Fatal Crashes



Miles



Vehicle Miles Traveled



"Rural" refers to a non-municipal area and cities with a population less than 5,000.

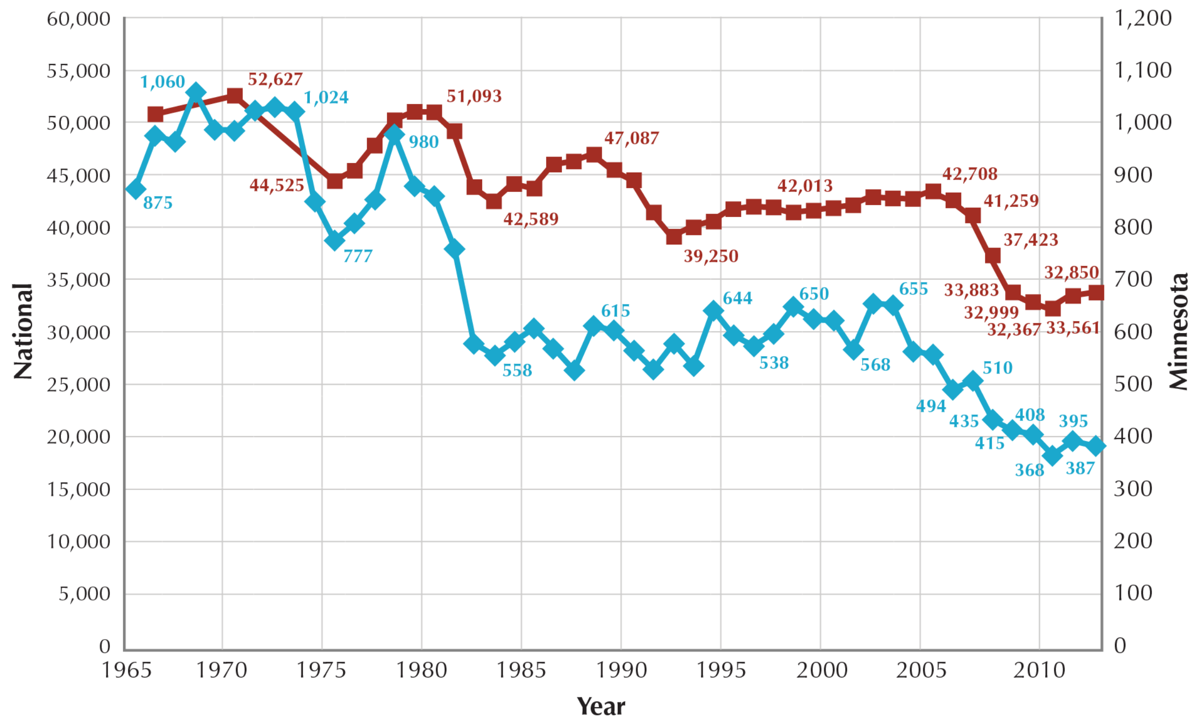
MnDOT TIS, 2009-2013

Highlights

- The total number of crashes is typically a function of exposure (VMT).
- In Minnesota, approximately 40% of the VMT is in urban areas and approximately 60% of the total number of statewide crashes are in urban areas.
- However, 77% of the fatal crashes in Minnesota are in rural areas.
- On average, rural crashes tend to be more severe than urban crashes – the fatality rate on rural roads is more than 2.5 times the rate in urban areas.
- The higher severity of rural crashes appears to be related to crash type, speed, and access to emergency services.

AASHTO's Strategic Highway Safety Plan

Persons Killed in Traffic Crashes

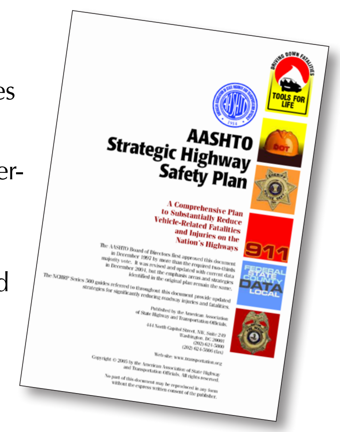


National Highway Traffic Safety Administration (NHTSA)

Note: 2013 fatalities from FARS statistical projections

Highlights

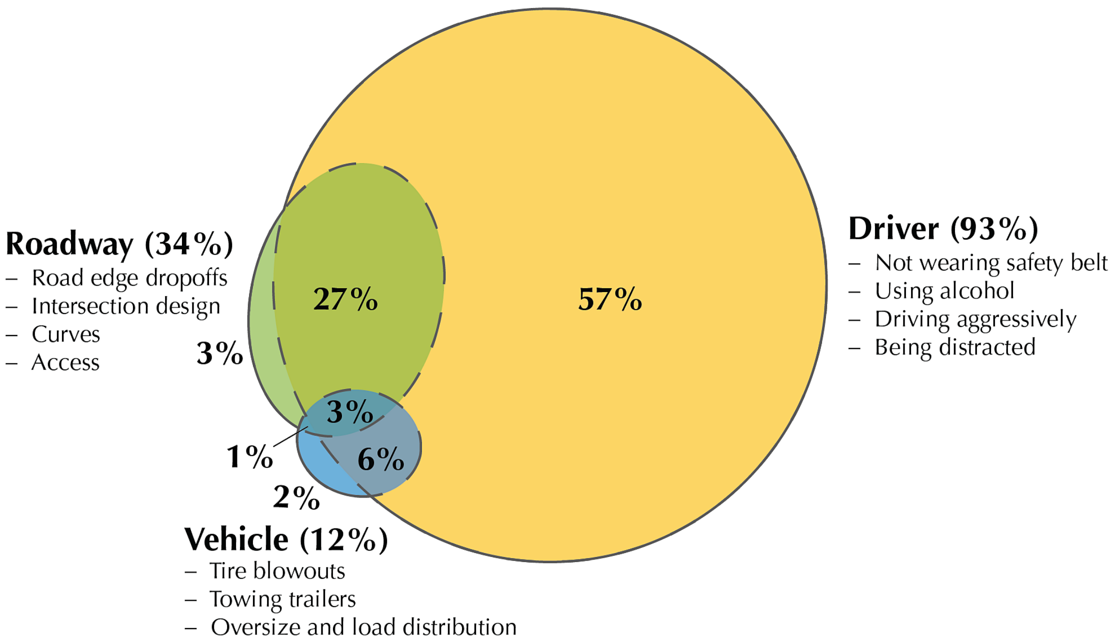
- In the 1990s, AASHTO concluded that historical efforts to address traffic safety were not sufficient to cause a continued decline in the annual number of traffic fatalities.
- AASHTO's Strategic Highway Safety Plan was first published in 1997 and then updated in 2004.
- The plan suggested setting a new *national safety performance measure* – the number of traffic fatalities and setting a goal to reduce the nation's highway fatality rate to not more the one fatality per 100 million VMT by 2008.
- The 2004 plan introduced innovative ideas, including:
  - Shared Responsibility – all roads, all levels of road authorities
  - Safety Emphasis Areas
  - Focus on Proven Strategies
  - Consideration of Driver, Roadway and Vehicle interactions when analyzing crash causation
  - Development of State and Local Comprehensive Safety Plans



Role of Driver, Road, and Vehicle

Crash Causation Factors

In this example, roadways are the sole contributing factor in 3% of crashes and the roadway and driver interaction is the factor in 27% of crashes.



The Role of Perceptual and Cognitive Filters in Observed Behavior, Kåre Rumar, 1985

Highlights

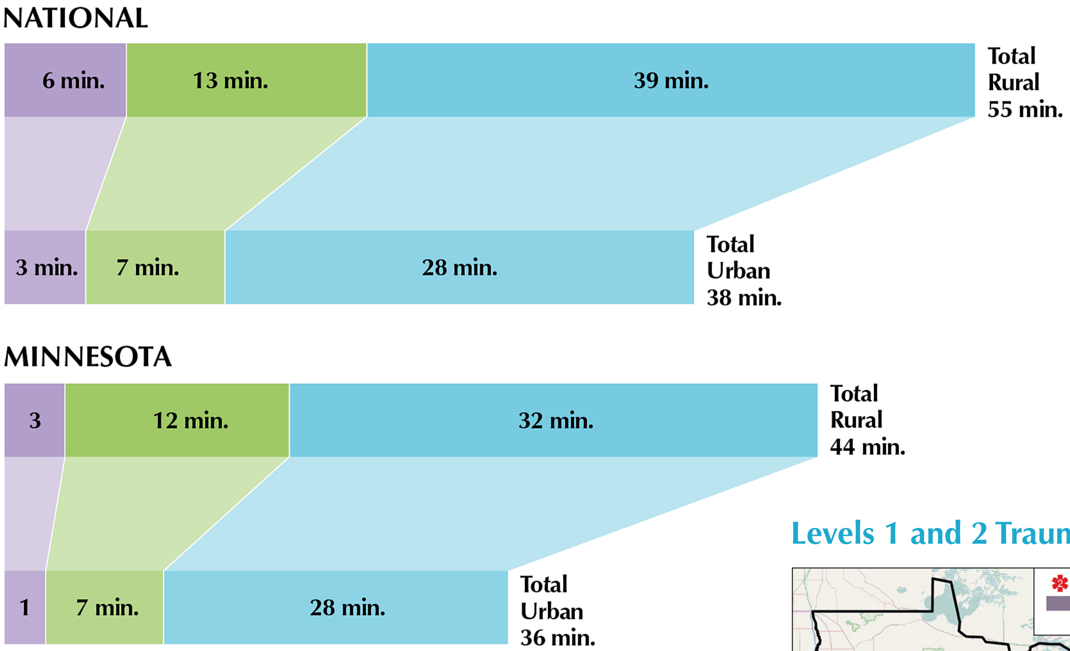
- Factors that contribute to serious crashes involve drivers, the roadway, and vehicles:
  - Driver behaviors that contribute to crashes include not wearing a safety belt, using alcohol, being distracted, and driving aggressively. Driver behaviors are a factor in 93% of crashes.
  - Roadway features include road edges, curves, and intersections. Roadway features are a factor in 34% of crashes.
  - Vehicle equipment failures, including tire blowouts, towing trailers, over size and load distribution. Vehicle failures are a factor in 12% of crashes.
- Studies have shown that safety programs that address multiple factors of the four Safety E's – Education, Enforcement, Engineering, and Emergency Services – will be the most effective.
- Examples of education and enforcement programs include the Department of Public Safety's Project Night Cap (alcohol) and CLICK IT or Ticket (safety belt usage).

NIGHT CAP

CLICK IT OR TICKET DAY & NIGHT

Emergency Response Time Comparison

National EMS Response Time



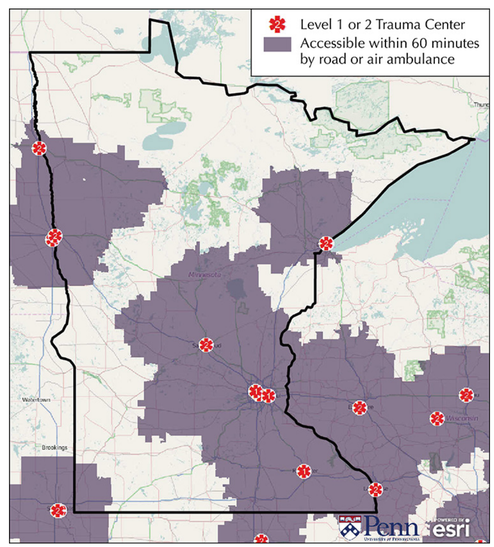
- Time of Crash to Time of Notification
- Time of Notification to Time of Arrival at Scene
- Time of Arrival at Scene to Time of Arrival at Hospital

Times are rounded to the nearest minute.

"Rural" refers to a non-municipal area and cities with a population less than 5,000.

National Highway Traffic Safety Administration (NHTSA)

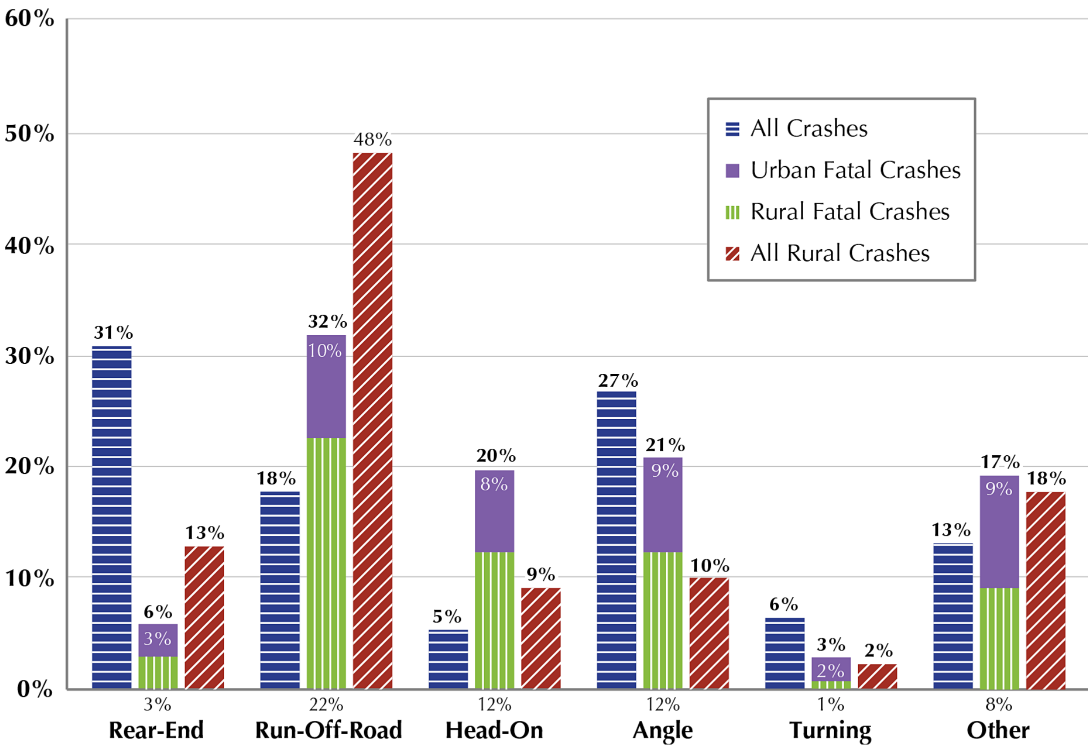
Levels 1 and 2 Trauma Centers



Highlights

- It appears that Emergency Response time may be a significant contributing factor to the higher frequency of fatal crashes in rural areas.
- Nationally, response times in rural areas average 55 minutes and are almost 45% longer than in urban areas.
- In Minnesota, the average rural response time is 44 minutes, which is among the lowest in the country and is the lowest response time in any state in the upper Midwest.
- The higher frequency of fatal crashes in rural areas, combined with the longer EMS response times, has led to discussions in both Minnesota and nationally, about how to both reduce response times and to improve outcomes for the seriously injured. In Minnesota, two techniques are widely used to address response times: the use of Air Ambulance in urban areas with large numbers of signals along arterial corridors and Emergency Vehicle Preemption of traffic signals.
- Minnesota has widely distributed air ambulance bases which provide coverage to all parts of the state and transport crash victims to 15 level I and II trauma centers.

Fatal Crashes Are Different

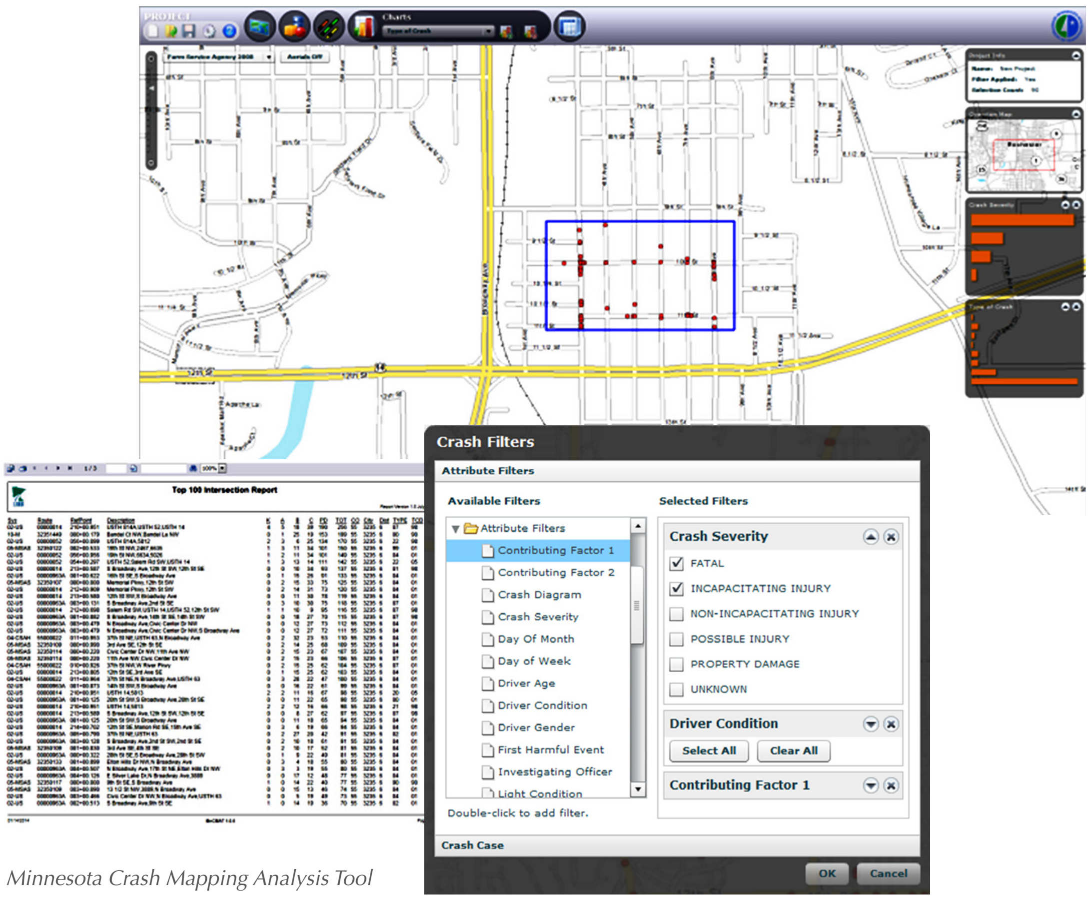


Minnesota Crash Mapping Analysis Tool, 2009-2013

Highlights

- For the past 30 years, the primary safety performance measure was the total number of crashes. This process resulted in safety investments being focused on locations with the highest number of crashes, which also have larger numbers of the most common types of crashes.
- The most common types of crashes in Minnesota are Rear-End (31%) and Right Angle (27%). These crashes occur most frequently at signalized intersections along urban/suburban arterials, which became the focus of safety investment.
- One problem with directing safety investments towards signalized urban/suburban intersections is that there was little effect on reducing fatalities – only about 10% of fatal crashes occur at these locations.
- The advent of Minnesota's Toward Zero Deaths (TZD) program and the 2003 adoption of a fatality-based safety performance measure led to research that first identified that fatal crashes are different from other less severe crashes.
- Fatal crashes are overrepresented in rural areas and on the local road system. The most common types of fatal crashes are Run-Off-Road (22%), Right Angle (12%), and Head-On (12%).
- These facts about fatal crashes have changed MnDOT's safety investment strategies, which are now focused on road departures in rural areas and on local systems.

Minnesota's Crash Mapping Analysis Tool (MnCMAT)

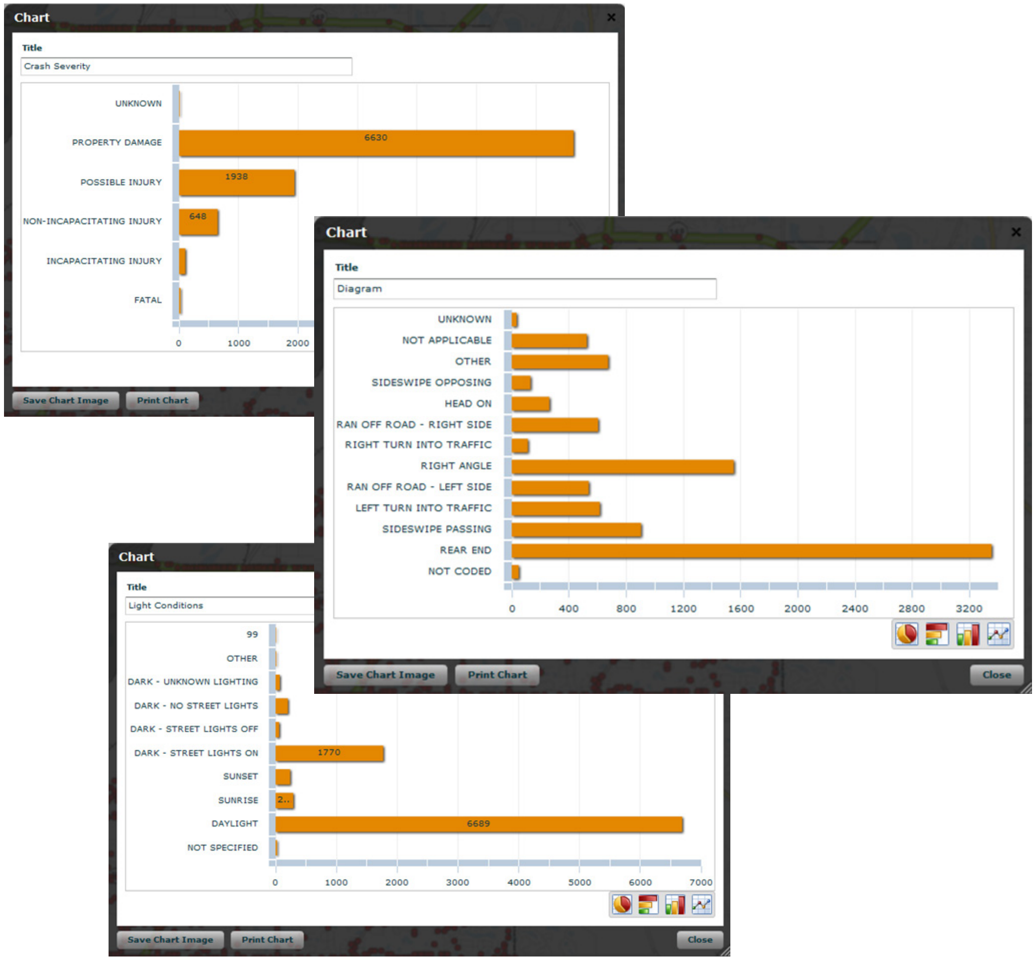


Minnesota Crash Mapping Analysis Tool

Highlights

- In order to assist cities and counties in gaining a better understanding of crash characteristics on their systems, MnDOT State Aid for Local Transportation, the Minnesota Local Road Research Board and Minnesota County Engineers Association (MCEA) have made an online tool available - the Minnesota Crash Mapping Analysis Tool (MnCMAT).
- MnCMAT is a map-based computer application that provides 10 years of crash data for all public roads in Minnesota.
- Individual crashes are located spatially by reference point along all roadways in the state.
- Up to 67 pieces of information are provided for each crash, including route, location (reference point), date/day/time, severity, vehicle actions, crash causation, weather, road characteristics, and driver condition.
- Outputs that can be generated from the application for analysis purposes include maps, crash data exports, charts, and reports.
- Analysts can select specific intersections or roadway segments for study. An overview of the entire state, MnDOT district, county, city, or tribal government can also be generated.
- For more information about MnCMAT and to access the online application, see **www.dot.state.mn.us/stateaid/crashmapping.html**.

Minnesota's Crash Mapping Analysis Tool (MnCMAT)

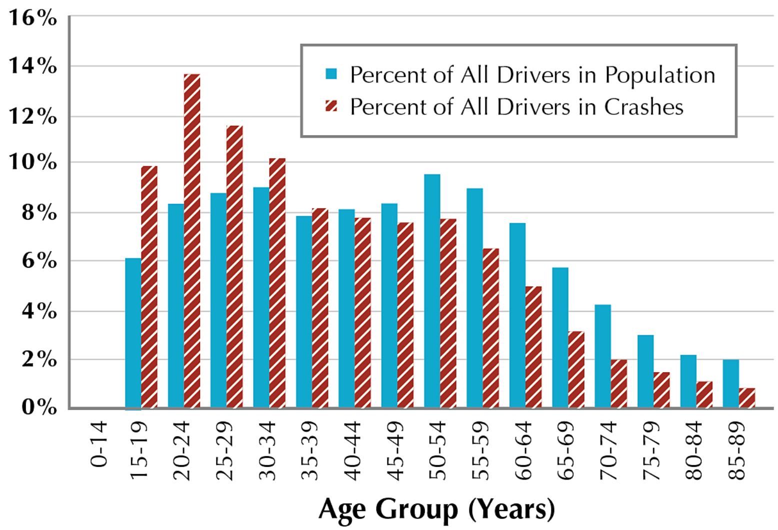


Minnesota Crash Mapping Analysis Tool

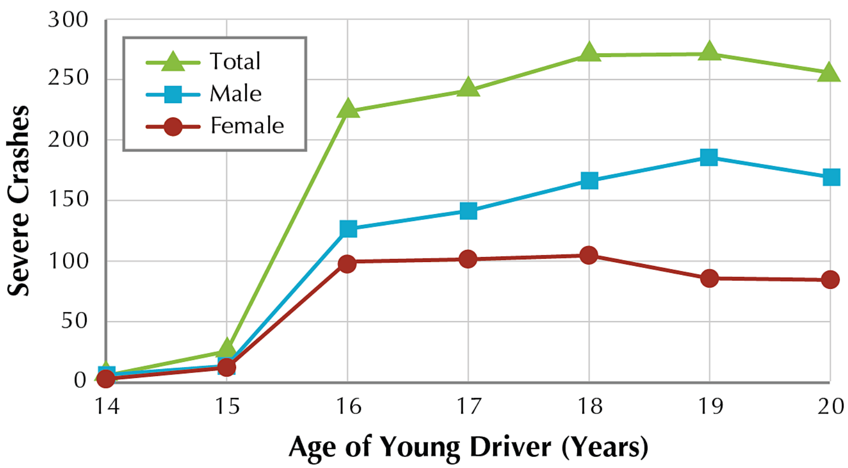
Highlights

- The recommended analytical process for conducting a safety/crash study is to compare actual conditions at a specific location (intersection or segment of highway) compared to expected conditions (based on documenting the average characteristics for a large system of similar facilities).
- MnCMAT supports this analytical process by providing both the data for individual locations and for larger systems – individual or multiple counties.
- The data in these graphs indicate that crashes for the selected area predominately occur under daylight conditions and a majority are rear-end and right angle crash types. Additionally, the graphs show the distribution of crashes by severity.

Crash Involvement by Age and Gender



2013 Minnesota Motor Vehicle Crash Facts



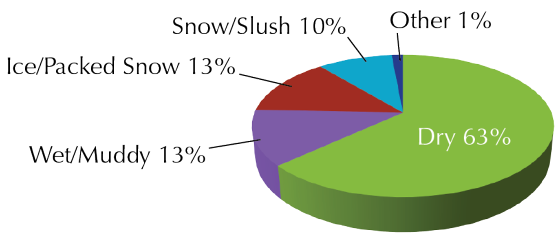
MnDOT TIS, 2009-2013

Highlights

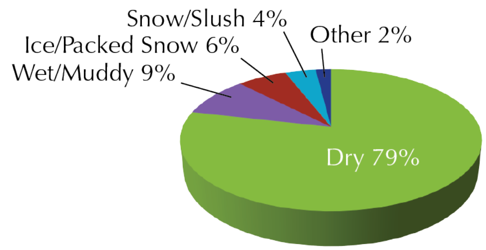
- The distribution of fatal crashes and total crashes by age indicates that young people are overrepresented.
- Minnesota's Strategic Highway Safety Plan has documented that young drivers (under 21 years old) are involved in 24% of fatal crashes. As a result, addressing young driver safety issues has been adopted as one of Minnesota's safety focus areas.
- One strategy has been found to be particularly effective at reducing the crash involvement rate of young drivers – adoption of a comprehensive Graduated Drivers License (GDL) program. The Minnesota Legislature took a step in this direction in 2008 by adding provisions that prohibit driving between midnight and 5 a.m. during the first 6 months of licensure and limiting the number of unrelated teen passengers during the first 12 months of licensure. Since adoption of this more comprehensive GDL, the number of severe crashes involving young drivers has dropped by an average of 13% per year (compared to a 4.5% per year drop in all severe crashes).
- Encouraging driver education providers to require a parent education component is demonstrating promising results in engaging parents to more effectively monitor and coach their teen driver. Education programs incorporating both parent and teen education help parents understand the importance of teen driving restrictions to reduce driving risk as novice drivers gain experience. The Minnesota Office of Traffic Safety (OTS) developed the nationally recognized Point of Impact: Teen Driver Safety Parent Awareness Program as a community-based class for parents and their teen drivers.

Total Crashes by Road, Weather, and Lighting Conditions

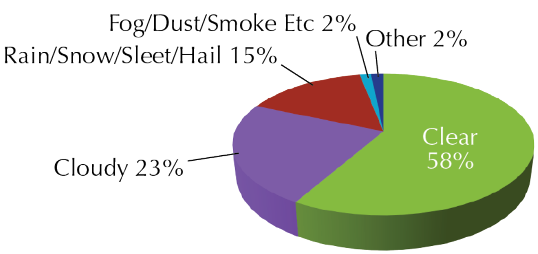
All Crashes

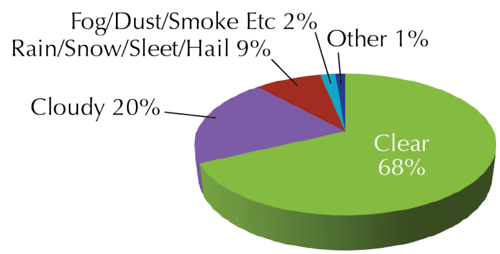


Fatal Crashes

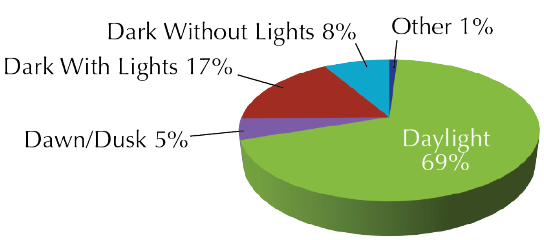


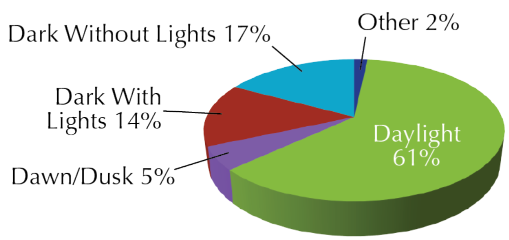
Weather Conditions





Lighting Conditions





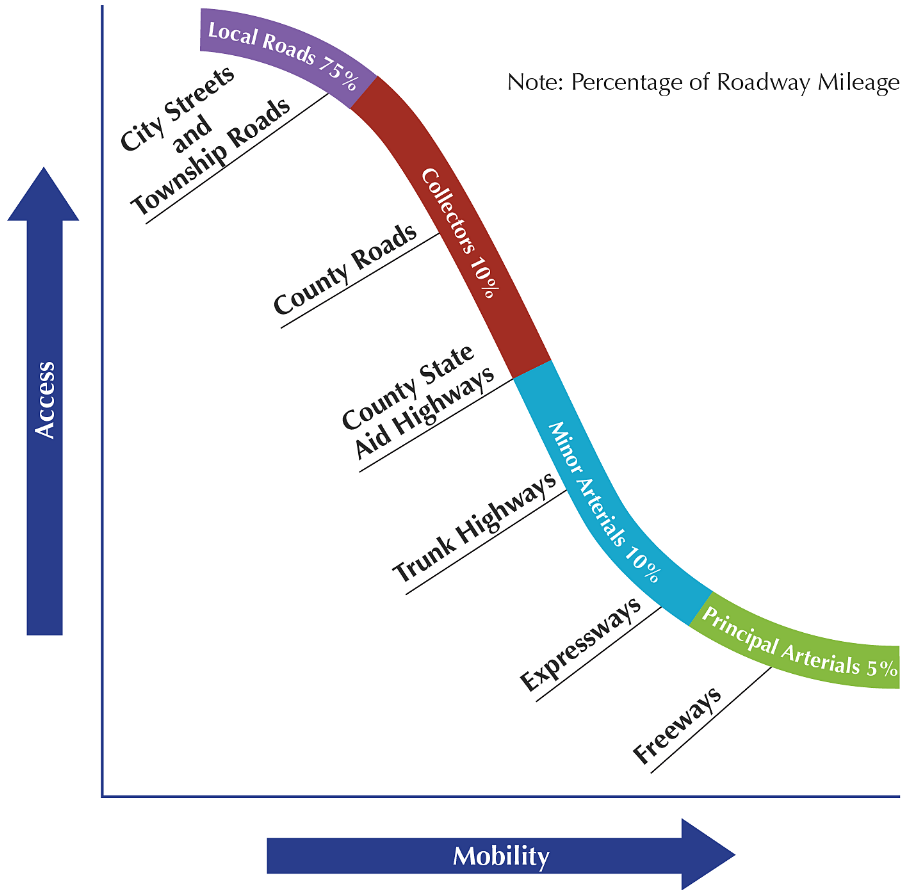
Minnesota Crash Mapping Analysis Tool, 2009-2013

Highlights

- Some elements of traffic safety are counterintuitive. Many people think that most crashes occur at night or during bad weather. However, the data clearly indicates that crash frequency is a function of exposure. Most crashes occur during the day on dry roads in good weather conditions.
- It should be noted that some research[1] has looked at safety issues during nighttime hours and during snow events. The research concludes that the conditions represent a significant safety risk because low level of exposure results in very high crash rates.
- In addition, the new focus on fatal crashes reinforces the concern about nighttime hours being more at risk – approximately 25% of VMT occurs during hours of darkness, but 31% of fatal crashes.

[1] MnDOT Research Report 1997-17, Table 5.4, estimated based on a sample from MnDOT's Automatic Recording Stations.

Access vs. Mobility – The Functional Class Concept

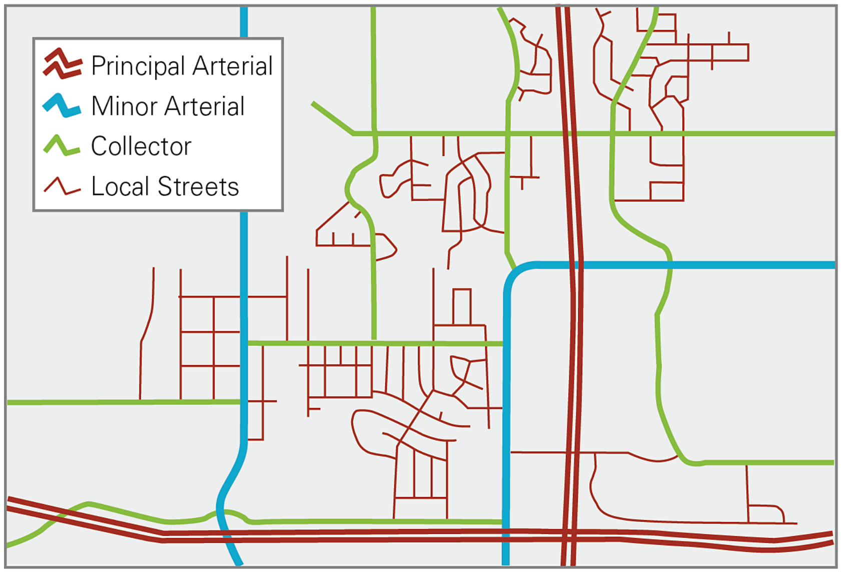


FHWA Publication No. FHWA-RD-91-044 (Nov 1992)

Highlights

- One of the key concepts in transportation planning deals with the functional classification of a road system. The basic premise is that there are two primary roadway functions – access and mobility – and that all roadways serve one function or the other, or in some cases, both functions.
- The four components of most functionally classified systems include Local Streets, Collectors, Minor Arterials, and Principal Arterials.
- The primary function of local streets is land access, and the primary function of principal arterials is moving traffic. Collectors and minor arterials are usually required to serve some combination of access and mobility functions.
- Key reasons supporting the concept of a functionally classified system include the following:
  - It is generally agreed that systems that include the appropriate balance of the four types of roadways provide the greatest degree of safety and efficiency.
  - It takes a combination of various types of roadways to meet the needs of the various land uses found in most urban areas around the state.
  - Most agencies could not afford a system made up entirely of principal arterials. A region can be gridlocked if it is only served by a system of local streets.
  - Roadways that only serve one function are generally safer and tend to operate more efficiently. For example, freeways only serve the mobility function and as a group have the lowest crash rates and the highest level of operational efficiency.
  - Functional classification can be used to help prioritize roadway improvements.
- The design features and level of access for specific roadways should be matched to the intended function of individual roadways.
- The appropriate balance point between the competing functions must be determined for each roadway based on an analysis of specific operational, safety, design, and land features.

Typical Functionally Classified Urban System



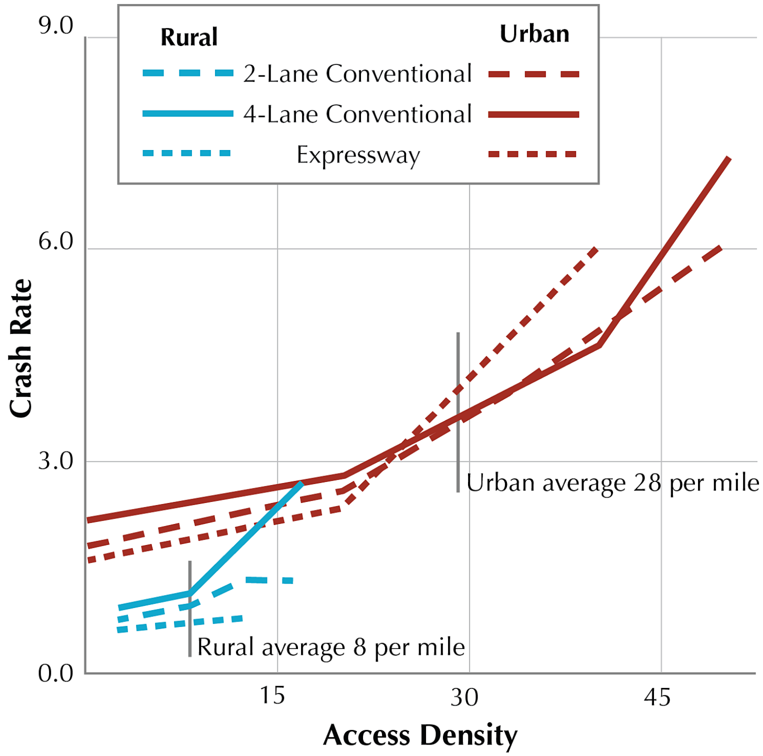
FHWA Publication No. FHWA-RD-91-044 (Nov 1992)

Highlights

- **Local Streets**
  - Low volumes (less than 2K ADT)
  - Low speeds (30 MPH)
  - Short trips (less than one mile)
  - Two lanes
  - Frequent driveways and intersections
  - Unlimited access
  - 75% system mileage / 15% VMT
  - Jurisdiction – Cities and Townships
  - Construction cost: $250K to $500K/mile
- **Collectors**
  - Lower volumes (1K to 8K ADT)
  - Lower speeds (30 or 35 MPH)
  - Shorter trips (1 to 2 miles)
  - Two or three lanes
  - Frequent driveways
  - Intersections to 1/8th mile spacing
  - 10% system mileage / 10% VMT
  - Jurisdiction – Cities and Counties
  - Construction cost: $1M to $2M / mile
- **Minor Arterials**
  - Moderate volumes (5K to 40K ADT)
  - Moderate speeds (35 to 45 MPH)
  - Medium length trips (2 to 6 miles)
  - Three, four, or five lanes
  - Only major driveways
  - Intersections at 1/4 mile spacing
  - 10% system mileage / 25% VMT
  - Jurisdiction – Counties and MnDOT
  - Construction cost: $2.5M to $7M / mile
- **Principal Arterials**
  - High volumes (greater than 20K ADT)
  - High speeds (greater than 45 MPH)
  - Longer trips (more than 6 miles)
  - 4 or more lanes – access control
  - Intersections at 1/2 mile spacing and Interchanges 1+ mile spacing
  - 5% system mileage / 50% VMT
  - Jurisdiction – MnDOT
  - Construction cost: $10M to $50M / mile

ADT	Average Daily Traffic
VMT	Vehicle Miles Traveled
MPH	Miles Per Hour
2K	2,000
1M	1,000,000

Roadway Segment Crash Rates as a Function of Facility Type and Access Density (MN)



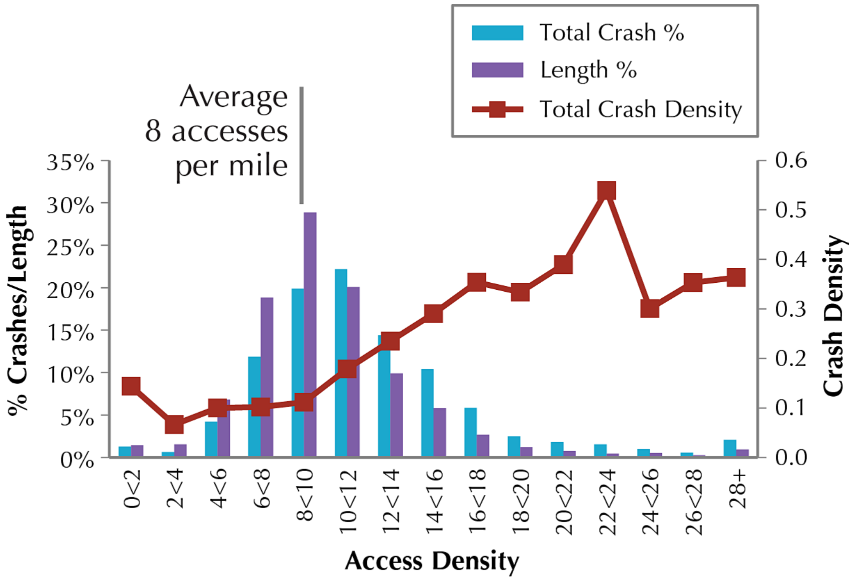
MnDOT Research Report 1998-27 "Statistical Relationship between Vehicular Crashes and Highway Access"

"Rural" refers to a non-municipal area and cities with a population less than 5,000.

Highlights

- Previous safety research going back 30 years indicated a potential relationship between access density and crash rates. However, this research did not account for other factors that are known to affect crash rates (rural vs. urban, design type of facility, etc.) and none of the data was from Minnesota.
- As a result, in 1998, MnDOT undertook a comprehensive review of the relationship between access and safety on Minnesota's Trunk Highway System. This effort ended with the publication of Research Report No. 1998-27, "Statistical Relationship Between Vehicular Crashes and Highway Access."
- The significant results include:
  - Documenting for the first time the actual access density (an average of 8 access per mile in rural areas and 28 access per mile in urban areas along State highways).
  - Observing a relationship between access density and crash rates in 10 of 11 categories.
  - Identifying a statistically significant tendency (in 5 out of 6 categories with sufficient sample size) for segments with higher access densities to have higher crash rates in both urban and rural areas.

Roadway Segment Crash Rates as a Function of Facility Type and Access Density (MN)



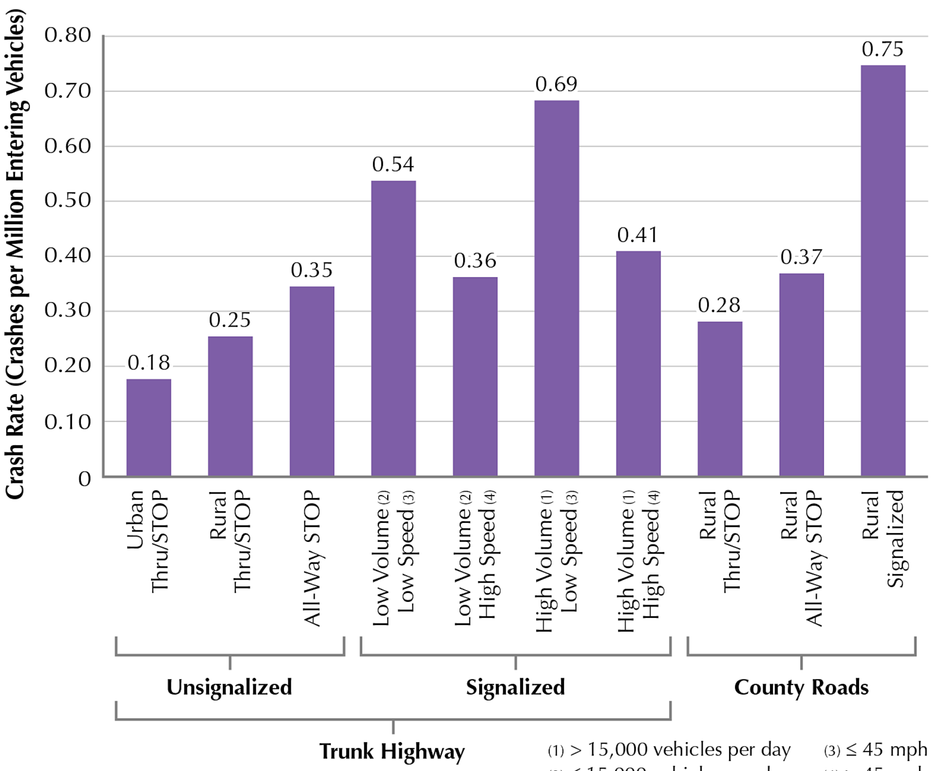
Minnesota County Road Safety Plans, Data 2007-2011

"Rural" refers to a non-municipal area and cities with a population less than 5,000.

Highlights

- MnDOT has completed the project that prepared a safety plan for every county in the state. One of the focus areas of the plans involved addressing severe crashes on rural county roadways. The analysis of Minnesota's crash records and the results of a systemwide risk assessment found a correlation between the density of access and crash density along 27,000 miles of rural county roadways. The higher the density of access, the higher the average crash density.
- The significant results include:
  - Documenting that the average access density for county roadways (approximately 8 per mile) is similar to rural, 2-lane state highways.
  - Observing a relationship between access density and crash density in segments with above average access density crashes are over-represented and the average crash density increases as access density increases.

Intersection Crash Rates (MN) by Control Type and Family

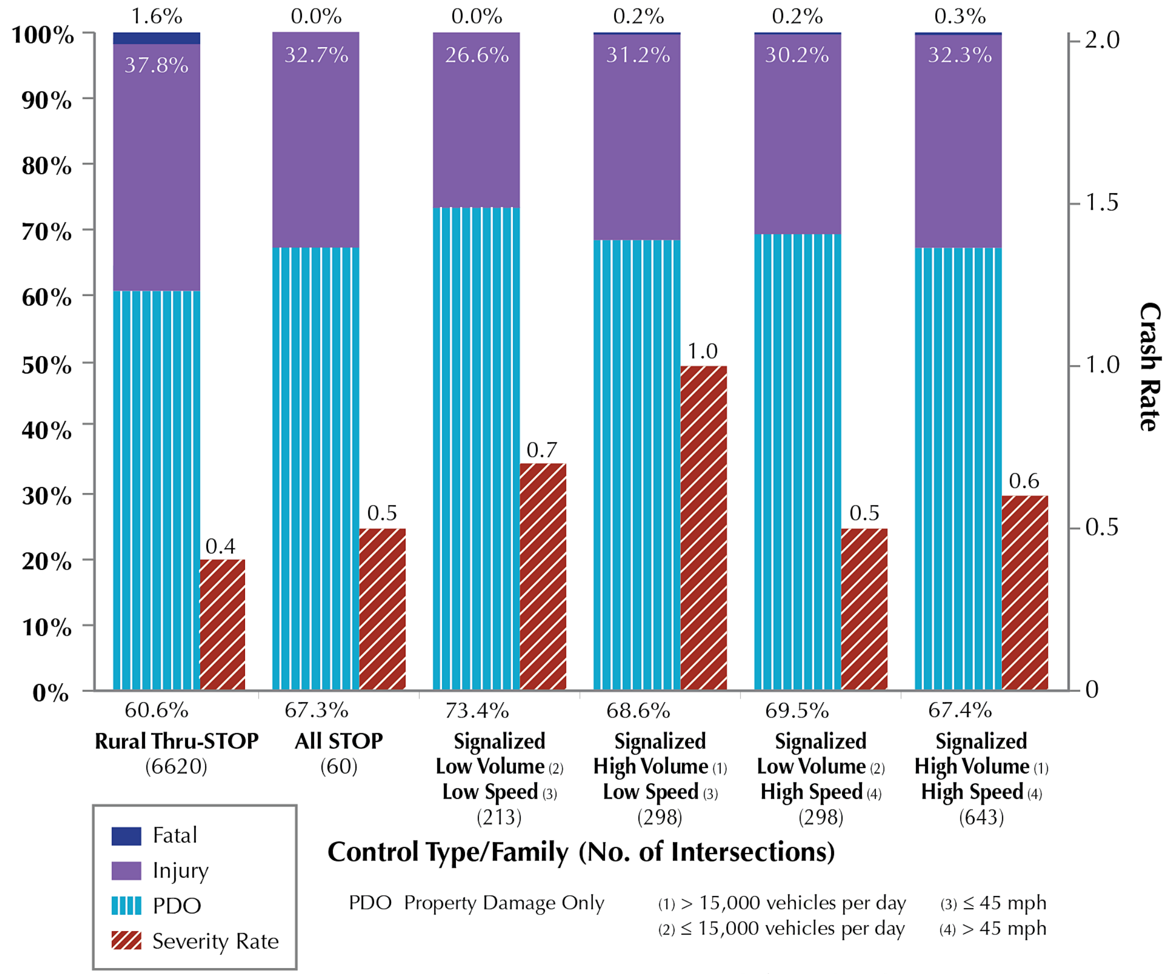


2013 MnDOT Crash Data Toolkit, 2011-2013, and Minnesota County Road Safety Plans, Data 2007-2011

Highlights

- Crash frequency at intersections tends to be a function of exposure – the volume of traffic traveling through the intersection. As a result, the most commonly used intersection crash statistic is the crash rate – the number of crashes per million entering vehicles (MEV).
- Crash frequency also tends to be a result of the type of traffic control at the intersection. Contrary to the popularly held opinion that increasing the amount of intersection control results in increased safety, the average crash rate at signalized intersections (0.5 per MEV) is more than 67% higher than average crash rate at stop sign-controlled intersections (0.3 per MEV). In addition, the average severity rate and the average crash density are also greater for signalized compared to stop sign controlled intersections.
- A wealth of research also supports the conclusion that traffic signals are rarely safety devices. Most before vs. after studies of traffic signal installations document increases in the number and rate of crashes, a change in the distribution of the type of crashes, and a modest decrease in the fraction of fatal crashes.
- As a result of crash characteristics associated with signalized intersections, installing traffic signals is NOT one of Minnesota's high priority safety strategies.
- There are also data to support a conclusion that some type of left turn phasing (either exclusive or exclusive/permitted), addressing clearance intervals and providing coordination helps to minimize the number of crashes at signalized intersections.
- The crash data documenting crash rates for intersections by type of control was previously limited to the State highway system. However, completion of the Country Road Safety Plans included analysis of almost 13,000 intersections along the county system. The results indicate that intersections along county roads have crash rates virtually identical to similar intersections along State highways.

Intersection Crash Severity (MN) by Control Type and Family



Control Type/Family (No. of Intersections)

PDO Property Damage Only

(1) > 15,000 vehicles per day
(2) ≤ 15,000 vehicles per day
(3) ≤ 45 mph
(4) > 45 mph

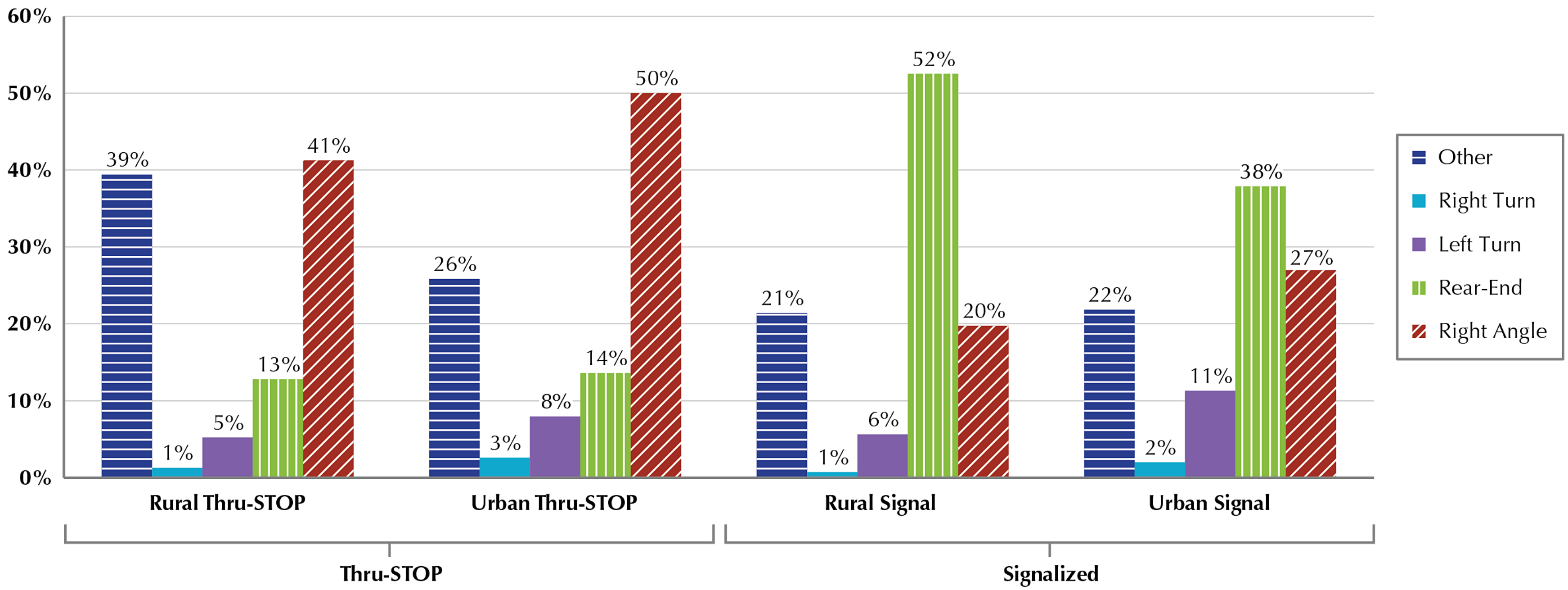
Note: Only for Trunk Highway Intersections

2013 MnDOT Crash Data Toolkit, 2011-2013

Highlights

- The distribution of intersection crash severity appears to be a result of the type/degree of intersection control methods. Based on a review of over 29,000 crashes at more than 8,100 intersections, low speed/low volume signalized intersections were found to have the highest percentage of property damage only crashes (73%) and the lowest percentage of injury crashes (27%). Intersections with All-way STOP control and low speed/low volume signalized intersections had the lowest percentage of fatal crashes (0.00%).
- The data also suggest that (on average) the installation of a traffic signal does not result in a reduction in crash severity. The severity rate at signalized intersections, ranging from 0.5 to 1.0, is about 25 to 50% higher than at intersections with Thru/STOP control (0.4).
- The data supports the theory that increasing the amount of intersection controls does not result in a higher level of intersection safety.

Intersection Crash Distribution by Control Type and Rural vs. Urban



Minnesota Crash Mapping Analysis Tool, 2009-2013

Highlights

- The crash type distribution that can be expected at an intersection is primarily a function of the type of intersection control.
- At stop-controlled intersections, in both rural and urban areas, the most common types of crashes are right angle and rear-end collisions.
- At signalized intersections, the most common types of crashes are rear-end, right angle, and left turn collisions.

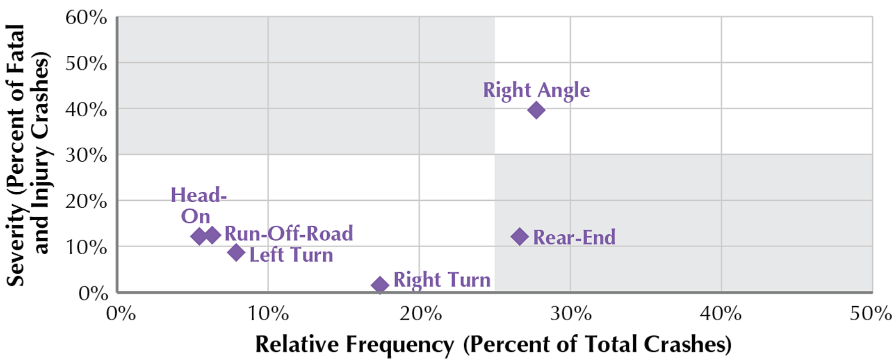
Key Points

- Traffic signals appear to reduce but not eliminate right angle crashes.
- Right turns present a very low risk of a crash (1% to 3% of intersection crashes).
- Left turns present a very low risk of a crash (5% to 11% of intersection crashes).
- Crossing conflicts present a very high risk of a crash (20% to 50% of intersection crashes).
- Rear-end conflicts present the highest risk of a crash (13% to 52% of intersection crashes).
- However, when severity is considered, a new picture emerges – see page A-21.

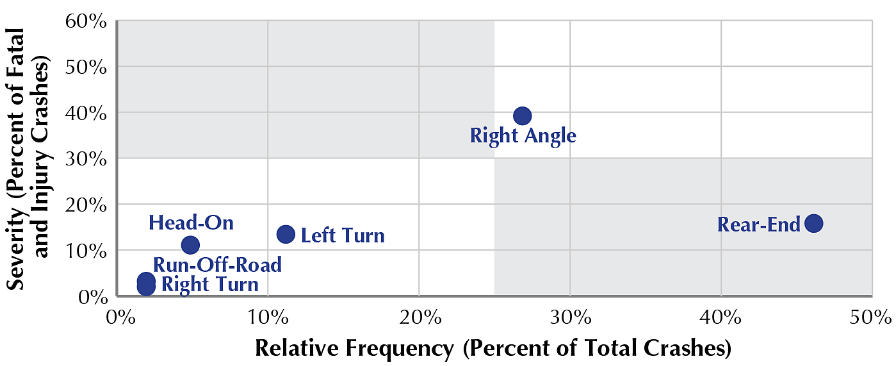
Intersection Crashes – Severity vs. Frequency

Severity/Frequency Combinations

All Intersection Crashes



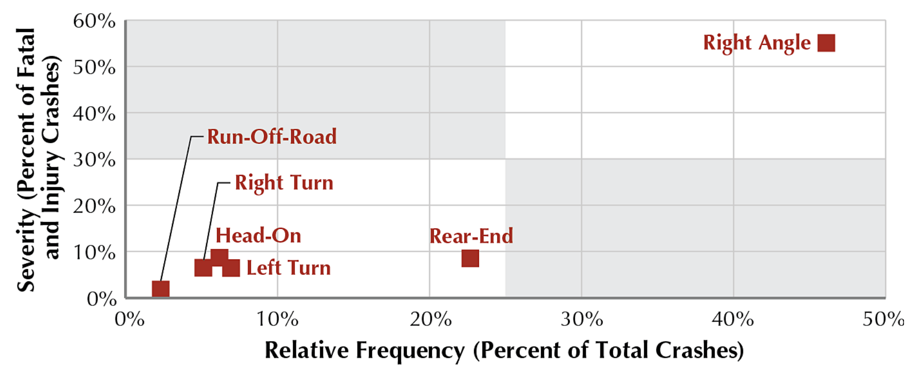
SIGNAL Controlled Intersection Crashes



Highlights

- When evaluating intersection-related crashes, a focus on severity results in a very different priority of crash types than if all crashes are considered.
- The most common type of severe intersection crash is a right angle collision.
- Right angle and rear-end crashes both account for approximately 27% of all intersection-related crashes. However, the right angle crash is almost FOUR times as likely to involve a fatality or serious injury.
- The least severe type of intersection-related crash involves right-turning vehicles, which account for approximately 2% of fatalities and serious injuries.
- This pattern is different when looking specifically at STOP controlled vs. Signal controlled intersections. At signalized intersections, over 45% of the crashes are rear-end; however, they account for only 15% of the severe crashes. Right angle crashes are the most common severe crash.
- For STOP controlled intersections, the right angle crash is the most common and most severe crash type.

STOP Controlled Intersection Crashes



Roadway Segment Crash and Fatality Rates by Jurisdictional Class

Roadway Jurisdiction Classification	Miles	Crashes	Fatalities	Crash Rate*	Fatality Rate**
Interstate	916	12,309	25	0.99	0.20
Trunk Highway	10,930	21,221	168	1.04	0.82
CSAH/County Roads	44,958	20,705	151	1.49	1.09
City Streets	22,373	21,975	24	2.42	0.26
Township & Other	63,799	1,497	19	1.21	1.53
State Total	142,976	77,707	387	1.36	0.68

2013 Minnesota Roadway & Crash Facts

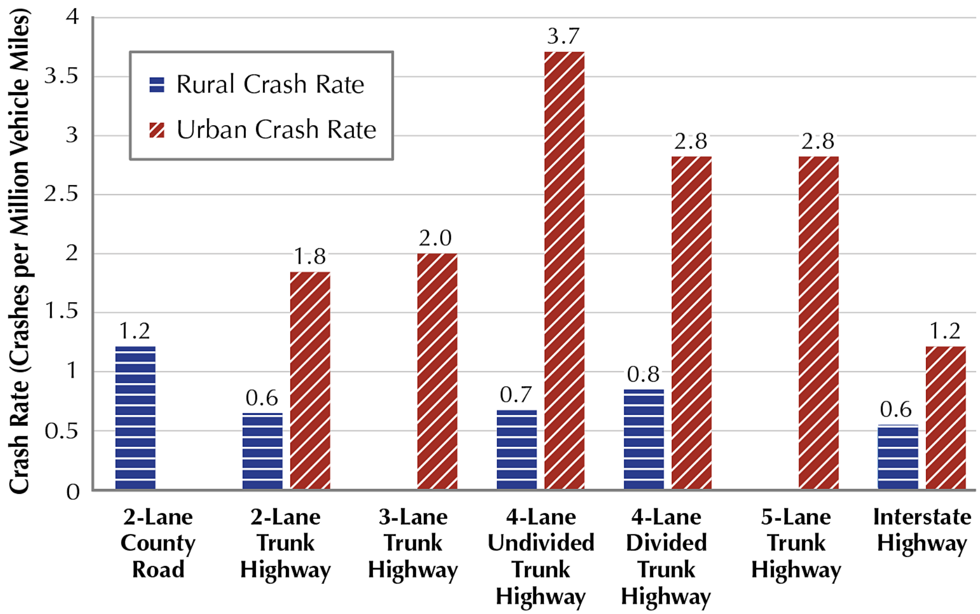
* per million vehicle miles (MVM)

** per 100 million vehicle miles (100 MVM)

Highlights

- As a class, interstates had lower crash and fatality rates than conventional roadways. This fact is likely due to three factors:
  - Interstates only serve a mobility function
  - Interstates tend to have a consistently high standard of design
  - Interstates have very strict control of access
- Of the conventional roadways, trunk highways had the lowest crash rate and the second-lowest fatality rate.
- City streets had the highest crash rate and a low fatality rate.
- County and township roads had moderately high crash rates and the highest fatality rates.
- This distribution of crashes generally supports the idea that greater numbers of crashes occur in urban areas and greater numbers of fatal crashes occur in rural areas.
- Crash rates and fatality rates by roadway jurisdiction (and for the state as a whole) are interesting; however, there is a great deal of evidence to suggest that crash rates are more a function of roadway design than who owns the road.

Roadway Segment Crash Rates
Facility Type by Rural vs. Urban

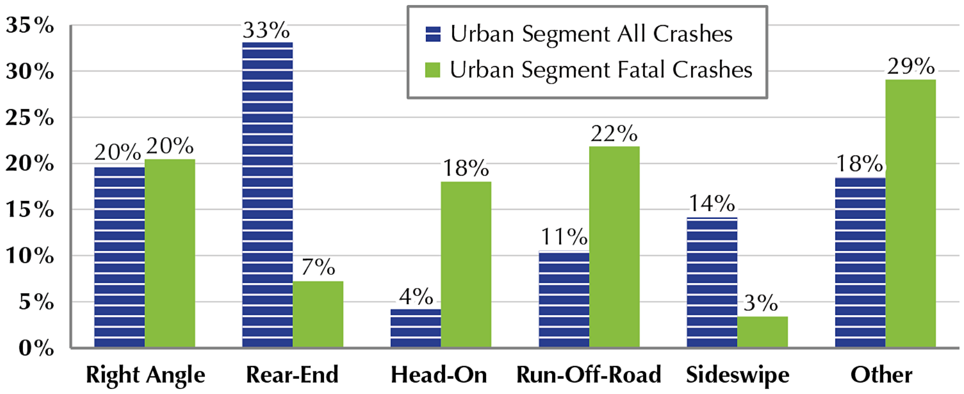


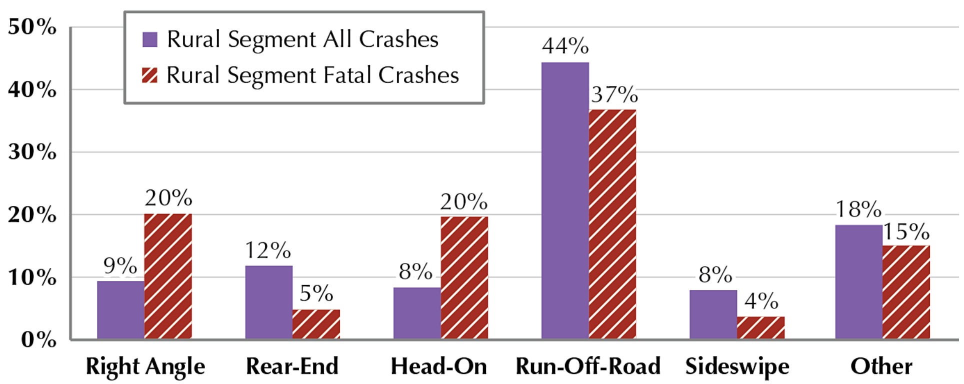
Minnesota County Road Safety Plans, Data 2007-2011
2013 MnDOT Crash Data Toolkit, 2009-2013

Highlights

- Average crash rates vary by location (rural vs. urban) and type of facility.
- Freeways have the lowest crash rates and are the safest roadway system in the state.
- Rural roadways as identified in the Toolkit have lower crash rates than similar urban roads.
- Urban conventional roadways (not freeways or expressways) – often minor arterials which serve both a mobility and land access function – have the highest crash rates.
- Four–lane undivided roadways have the highest crash rate; these facilities are usually found in commercial areas with high turning volumes and with little or no management of access. Over the years, the average has been lowered (from a rate of 8.0 in 1990) due to MnDOT's efforts to convert the worst segments to either three-lane, four-lane divided, or five-lane roads. The addition of left turn lanes to segments of urban conventional roadways typically reduces crashes by 25% to 40%.
- The distribution of crash rates by facility type points to the following relationship between access density and safety: highways with low levels of access (freeways) have low crash rates, and highways with higher levels of access (conventional roads) have comparatively higher crash rates.

Roadway Segment Crash Distribution by Rural vs. Urban





Minnesota Crash Mapping Analysis Tool, 2009-2013

Highlights

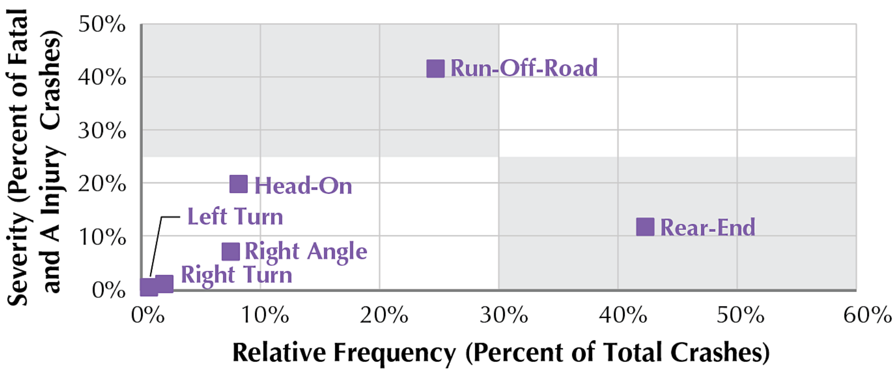
- There is a significant difference in the types of crashes that occur on urban versus rural roads.
- Urban crashes are predominately two-vehicle (about 85%), and rural crashes are predominately single-vehicle (about 55%).
- The most common types of urban crashes include:
  - Rear-end – 33% of all crashes and 7% of fatal crashes
  - Right angle – 20% of all crashes and 20% of fatal crashes
- The most common types of rural crashes include:
  - Run-off-road – 44% of all crashes and 37% of fatal crashes
  - Rear-end – 12% of all crashes and 5% of fatal crashes
  - Right angle – 9% of all crashes and 20% of fatal crashes
- Some types of crashes are more severe than others. Only 8% of all rural crashes involve head-on collisions, but they account for 20% of the fatal crashes.
- Deer hits are underreported because they rarely result in injury to vehicle occupants. A conservative estimate is that as many as 24% of rural crashes involve hitting a deer. State Farm Insurance estimates indicate that there were approximately 40,000 deer hits in Minnesota in 2012. For more information about collisions involving a deer, see **www.deercrash.org**.
- The distribution of crashes reinforces the safety priorities established for both State and local system roadways – right angle and rear-end crashes in urban areas and run-off-road, right angle and head-on in rural areas.

Segment Crashes – Severity vs. Frequency

Severe & Not Frequent	Severe & Frequent
Not Severe & Not Frequent	Not Severe & Frequent

Severity/Frequency Combinations

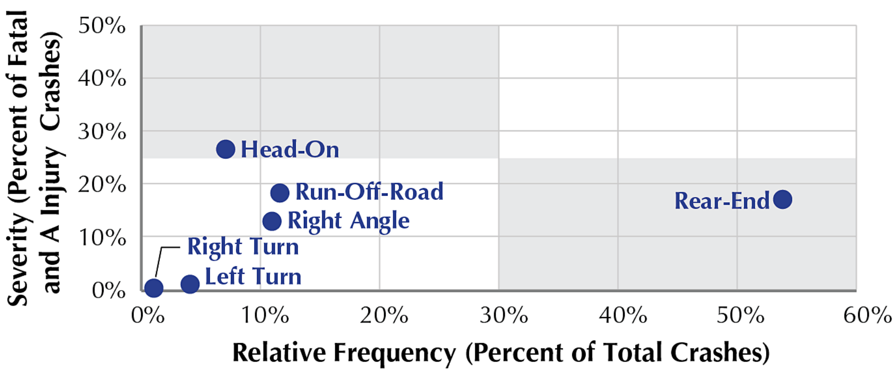
All Segment Crashes



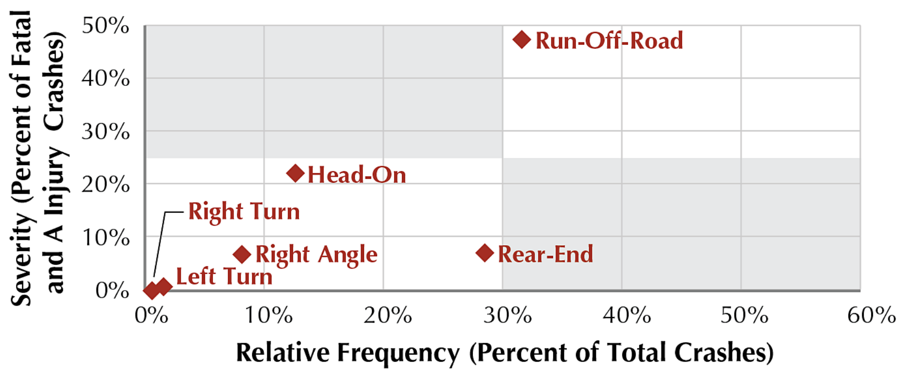
Highlights

- The most common type of segment-related crash is a rear-end collision (42%). However, rear-end collisions account for only around 12% of serious crashes.
- Run-off-road crashes are the most common type of severe crash, accounting for 24% of the crashes and over 40% of the fatal and serious injury crashes.
- Head-on crashes are the second-most severe type of crash, accounting for 8% of all segment-related crashes but 20% of serious crashes.
- Segment-related crashes involving right and left turning vehicles are both infrequent (fewer than 5% of crashes) and rarely severe (fewer than 5% of serious crashes).

Segment Crashes – Multi-Lane Roadway

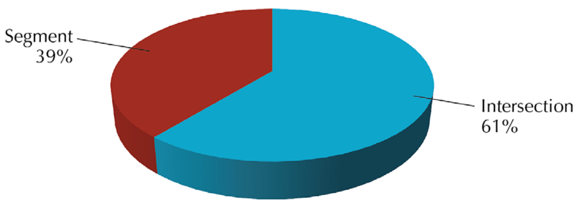


Segment Crashes – 2-Lane Roadway

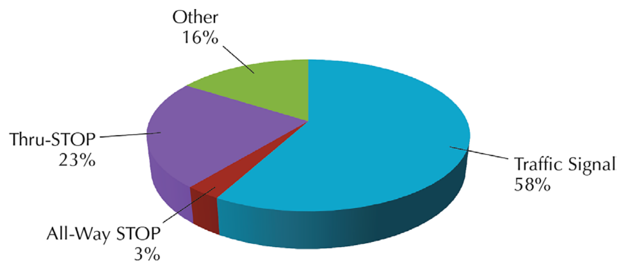


Pedestrian/Bicycle Crash Distribution by Intersection Control Type

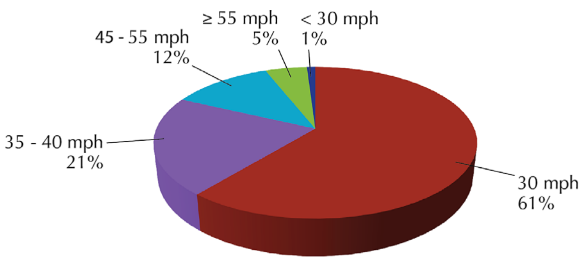
Crash Location



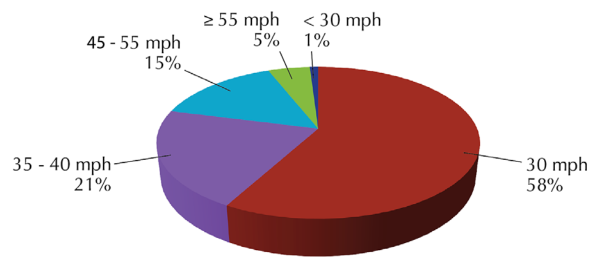
Intersection Type



Roadway Speed



Roadway Speed at Signalized Crashes

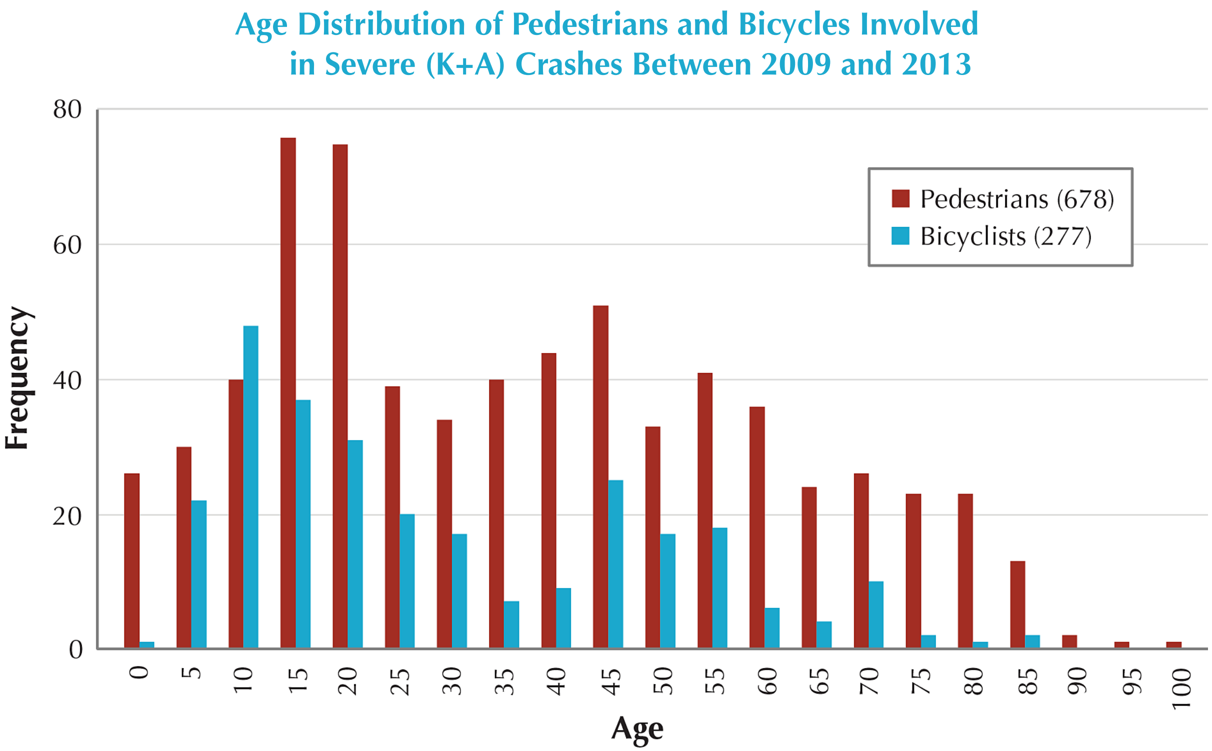


MnDOT TIS, 2009-2013

Highlights

- Minnesota averages 184 fatal and serious injury crashes involving pedestrians and bicycles per year (approximately 14% of all severe crashes).
- 66% of all serious pedestrian/bicycle crashes occur in the seven county Minneapolis/St. Paul metropolitan area.
- 61% of the serious pedestrian/bicycle crashes in the Metropolitan Area occur at an intersection and 81% are on the local (city and county) road system.
- 58% of the serious pedestrian/bicycle crashes occur at intersections controlled by traffic signals, in contrast 30% of intersections are traffic signals on the State system and 45% on the county system.
- Based on the distribution of crashes by intersection control type, it can be concluded that serious crashes involving pedestrians/bicycles are overrepresented at traffic signals.
- The data supports the conclusion that traffic signals alone are NOT safety devices for pedestrians or bicyclists. (See pages C-38 - C-41 for a discussion of pedestrian and bicycle safety strategies.)
- 61% of serious pedestrian/bicycle crashes occur on streets with a 30 mph speed limit and 82% of the crashes occur on streets with a speed limit of 40 mph or less.
- This data supports the conclusion that lower speed limits alone are not sufficient to eliminate the risk of traffic crashes for pedestrians and bicyclists.

Pedestrian/Bicycle Crash Distribution by Age



MnDOT TIS, 2009-2013

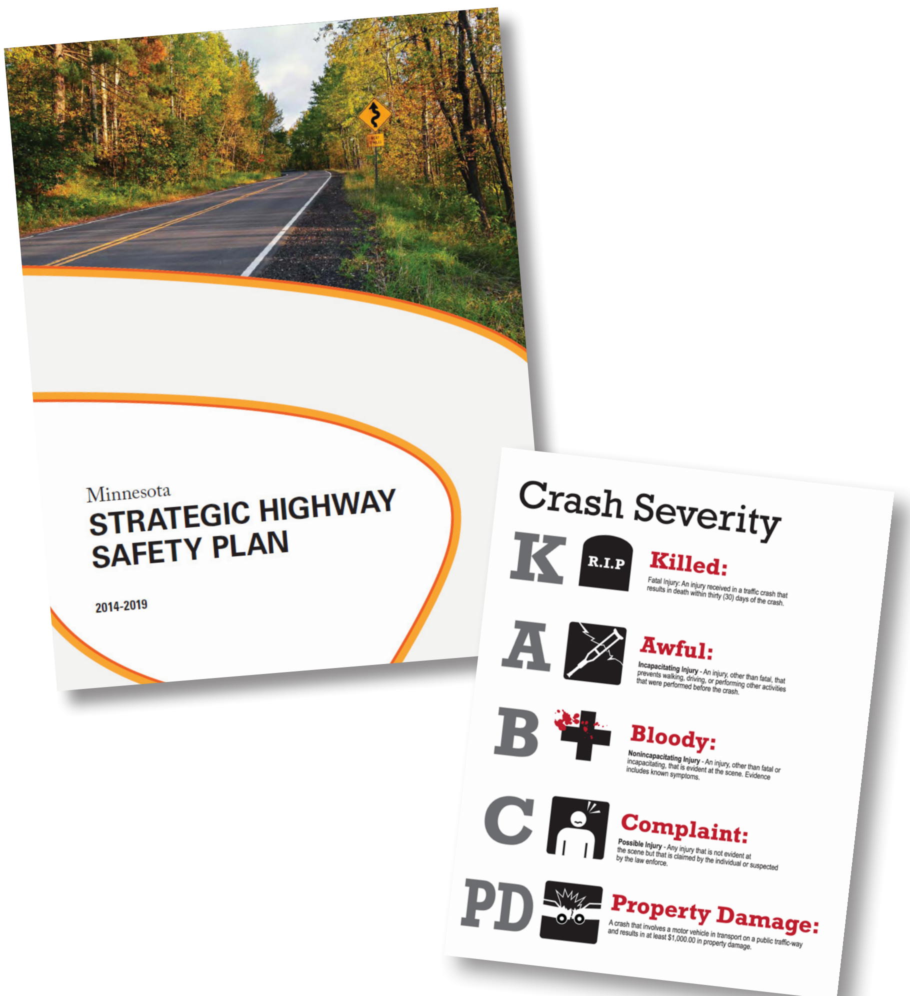
Highlights

- Pedestrians between the ages of 15 and 25 and those older than 65 are involved in 38% of serious injury crashes.
- Bicyclists between the ages of 10 and 25 are involved in 42% of serious injury crashes.
- Beyond the overall crash numbers, the involvement of each of these age groups was found to be over represented when normalized for population.

Section B

Safety Improvement Process

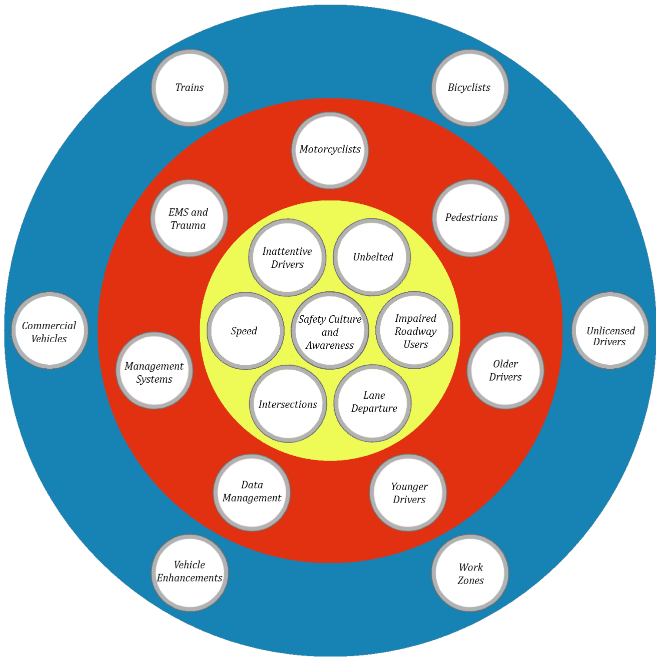
Minnesota's Strategic Highway Safety Plan (SHSP)



Highlights

- Minnesota Strategic Highway Safety Plan (SHSP) is a data-driven document that provides insight and direction on how to reduce traffic related crashes.
- The SHSP is intended to guide safety efforts during the next 5 years.
- It documents a new, short-term safety goal: 300 or fewer fatalities and 850 or fewer serious injuries by 2020.
- It adopts a long-term goal of ZERO fatalities and identifies changing the safety culture as a fundamental safety focus area.
- The SHSP notes that traffic fatalities have decreased by 40% during the past 10 years and attributes much of that success to the formation of Minnesota's Toward Zero Deaths program.
- The SHSP adopts severe crashes – those involving fatalities and incapacitating injuries as the safety performance measure in Minnesota.
- MnDOT SHSP web site: **www.dot.state.mn.us/trafficeng/safety/shsp/index.html**

Minnesota's Safety Focus Areas



2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- Guidance provided by FHWA and AASHTO suggests that state and local safety programs will be the most effective if their implementation efforts are focused on mitigating the factors that cause the greatest number of fatal crashes.
- An analysis of Minnesota's crash data documented the factors associated with fatal crashes; the results support designating the following seven high-priority safety focus areas:
  - Traffic Safety Culture
  - Intersections
  - Lane Departure
  - Unbelted
  - Impaired
  - Inattentive
  - Speeding
- MnDOT takes the lead in addressing the infrastructure-based focus areas by adopting a focus on lane departure crashes in rural areas, establishing goals for proactively deploying low-cost treatments widely across systems of roadways, and revising the management of the Highway Safety Improvement Program in order to direct more resources to those elements of the system that are most at risk – rural highways and county roadways.
- The Minnesota Department of Public Safety takes the lead in addressing the driver behavior-based focus areas, mostly through public outreach, education and high-visibility enforcement programs.

Safety Focus Areas – Greater Minnesota vs. Metro

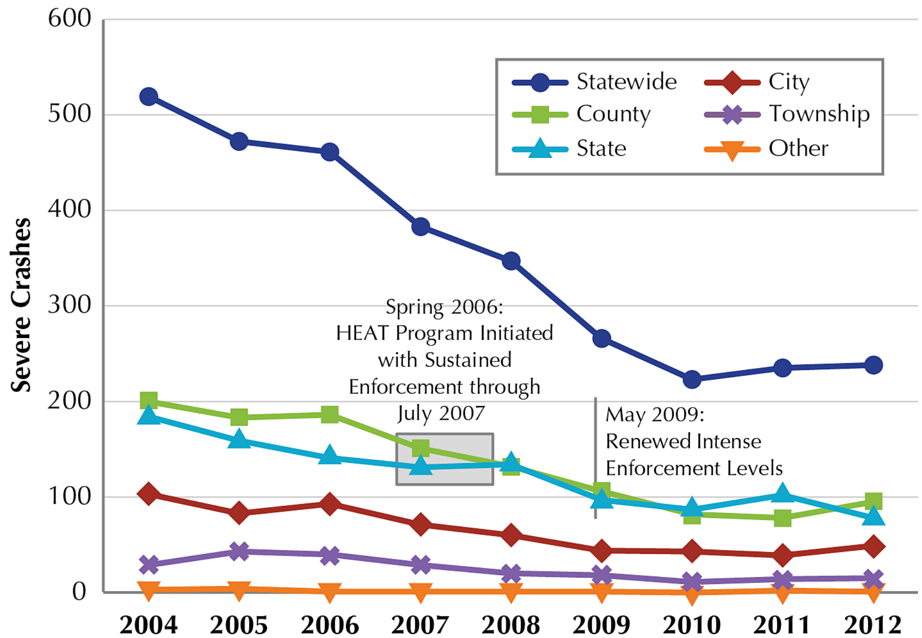
		Driver Behavior-Based Focus Areas				Infrastructure-Based Focus Areas	
	Total Severe Crashes	Unbelted	Impaired	Inattentive	Speeding	Lane Departure	Intersection
Statewide							
	7,036	2,463	1,850	1,319	1,309	3,199	2,945
Greater Minnesota Districts (2008-2012 Severe Crashes)							
State Trunk Highway	1,813	666	414	430	326	919	686
County Roads	1,699	743	580	309	342	1,017	545
City	435	141	99	70	87	146	224
Township	278	150	116	24	73	175	62
Other	17	3	9	1	4	9	2
Greater Minnesota Total	**4,242**	**1,703**	**1,218**	**834**	**832**	**2,266**	**1,519**
Metro District (2008-2012 Severe Crashes)							
State Trunk Highway	831	242	216	179	172	295	360
County Roads	1,148	285	223	200	151	386	668
City	786	222	182	106	148	237	391
Township	22	11	10	0	5	11	6
Other	7	0	1	0	1	4	1
Metro District Total	**2,794**	**760**	**632**	**485**	**477**	**933**	**1,426**

2014-2019 Minnesota Strategic Highway Safety Plan, Data 2008-2012

Highlights

- Approximately 60% of the serious crashes in Minnesota are in the 79 counties outside of the 8-county Minneapolis-St. Paul Metropolitan Area.
- Approximately 62% of serious crashes occur on the local roadway system, which also results in higher fatality rates on the local system.
- In rural areas, the primary factors associated with serious crashes are not using safety belts, impaired driving, and road departure.
- In urban areas, the primary factors associated with serious crashes are intersections, not using safety belts, impaired driving, and inattentive/distracted driving.

Behavioral Focus Area– Speeding

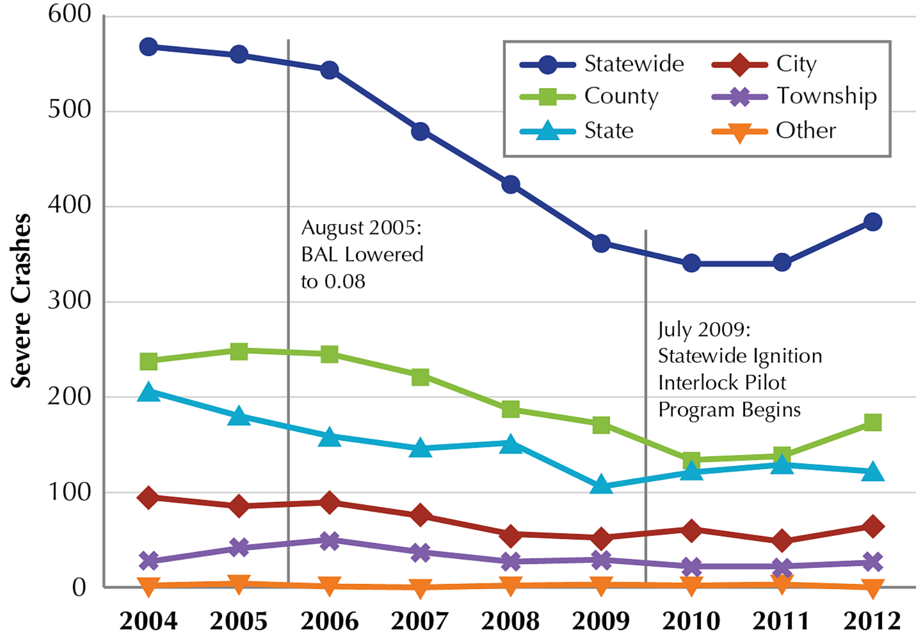


2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- On Minnesota roadways, there were 1,309 severe speeding-related crashes between 2008 and 2012. This is an average of 262 severe crashes per year, accounting for 19% of all severe crashes during the 5-year period.
- Severe crashes involving speed are notably represented within both state and local roadway systems, as well as in both rural (55%) and urban (41%) areas, as defined by investigating officers.
  - 70% of severe speeding-related crashes in rural areas occur on rural high-speed two-lane roads.
  - 58% of severe speeding-related crashes on rural county roads occur along curves, compared to 39% on all roadways statewide.
- Severe crashes involving speed occur among differing crash types:
  - 62% are lane departure crash types.
  - 70% of severe speed-related crashes occur on dry pavement.
- Drivers aged 35 and younger account for 63% of speeding-related severe crashes; 77% of drivers in severe speeding-related crashes are male.
- The number of speed-related crashes fell steadily between 2004 and 2010 and then flattened out.
- During the 2004 to 2010 timeframe, the State sponsored two enhanced enforcement campaigns (HEAT – High Enforcement of Aggressive Traffic) focused on ticketing speeding drivers and reducing the number of severe speeding-related crashes.
- Nearly equal numbers of speeding-related crashes occur on the state and county roadway systems and these systems experienced the greatest reduction over time.

Behavioral Focus Area– Impaired Driving

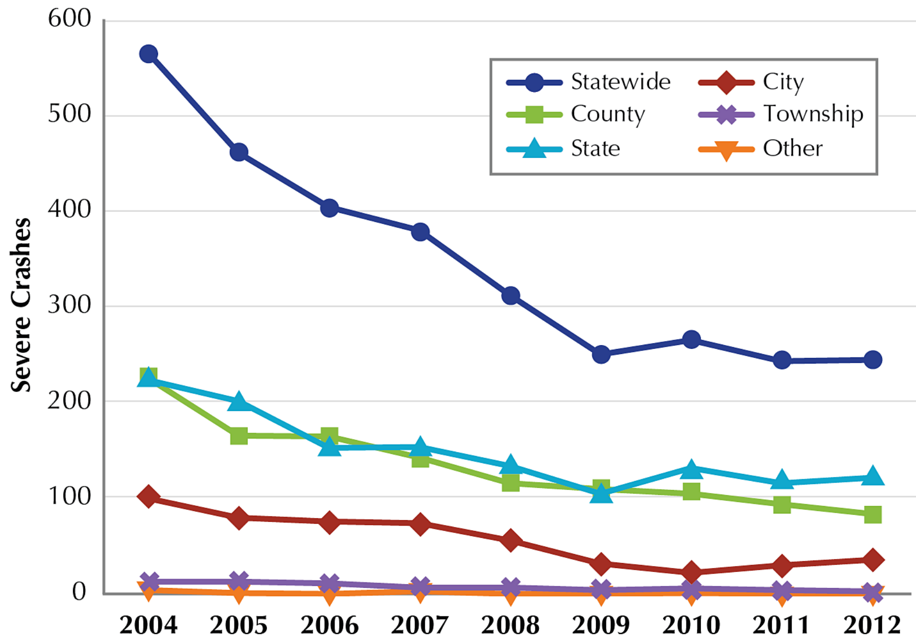


2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- On Minnesota roadways, there were 1,850 severe crashes involving impaired drivers and roadway users between 2008 and 2012. This is an average of 370 severe crashes per year and accounted for 26% of all severe crashes during the 5-year period.
- Severe crashes involving impaired roadway users occur across all roadway jurisdictions and in both rural and urban areas. However, most severe crashes occurred on rural roads (58%), as defined by investigating officers.
  - 74% of severe crashes involving impaired users in rural areas occur on rural, high-speed, two-lane roads.
- Lane departure accounts for 64% of all severe crashes involving impaired roadway users.
- Severe impaired-user crashes are nearly twice as likely to occur at night as the average for all severe crashes; 48% of severe impaired-user crashes occur between 9:00 PM and 3:00 AM.
- Overall, males and young adults are overrepresented in impaired-related crashes and account for a disproportionate share of fatalities. In 2013, males accounted for 67% of impaired-driving arrests. However, from 2003 to 2013, female DWI offenses increased 5%.
- The number of alcohol-related crashes fell steadily between 2004 and 2010, but has since increased slightly.
- During the 2004 to 2010 timeframe, the State adopted two new alcohol-related strategies: lowering the Blood Alcohol Concentration threshold from 0.1 to 0.08 and initiating the use of ignition interlock devices.
- Disaggregated by system, county roadways have had more alcohol-related crashes than state highways or city streets.

Behavioral Focus Area– Inattentive Driving

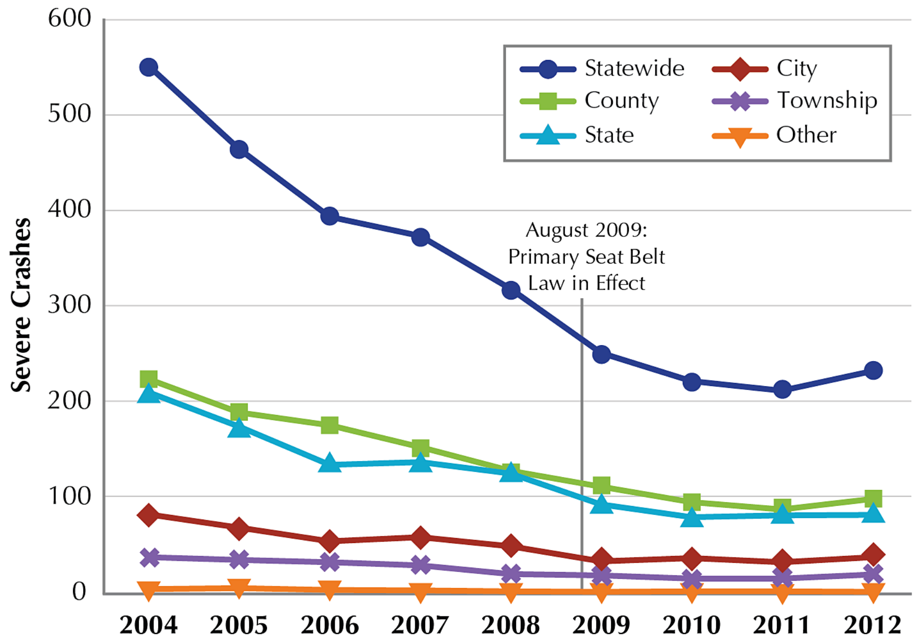


2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- While anything that takes your eyes off the road, hands off the wheel, or mind off driving is a hazard, texting/reading email/accessing the internet is particularly dangerous, by combining all three types of distraction – visual, manual, and cognitive.
- On Minnesota roadways, there were 1,319 severe crashes involving inattentive drivers between 2008 and 2012. This is an average of 264 severe crashes per year and accounted for 19% of all severe crashes during the 5-year period.
- The majority of severe inattentive driving crashes do not occur under adverse driving conditions:
    - 92% of these crashes occur during calm weather conditions (clear or cloudy).
    - 70% of these crashes occur during daylight.
    - 84% of these crashes occur on dry pavement.
- Severe crashes involving inattentive drivers occur among differing crash types, with 46% intersection-related and 39% lane departure-related.
    - Intersection crash types occur predominantly on straight segments (92%), but the presence of curves nearly doubles the occurrence of lane departure crash types (36%).
- Severe crashes involving inattentive drivers are notably represented in both rural (54%) and urban (44%) areas, as defined by investigating officers.
    - 71% of severe inattentive driving crashes in rural areas occur on rural two-lane roads with a high speed limit.

Behavioral Focus Area– Seat Belts

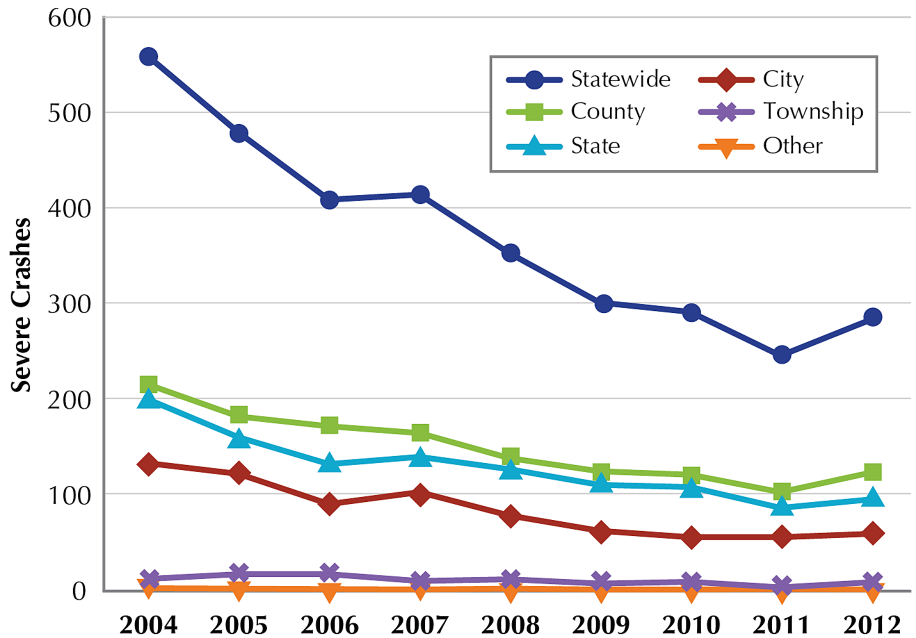


2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- On Minnesota roadways, there were 2,463 severe crashes involving an unbelted or improperly belted occupant between 2008 and 2012. This is an average of 493 severe crashes per year and accounted for 35% of all severe crashes during the 5-year period.
- Severe crashes involving unbelted or improperly belted occupants primarily occurred in rural areas (61%), as designated by investigating officers; the majority of these crashes occurred on local roadways (63%).
- 74% of severe crashes involving unbelted occupants in rural areas occur on rural, high-speed two-lane roads.
- Severe crashes involving unbelted drivers occur among differing crash types, with 42% as run-off-road crashes, as compared to 30% for all severe crashes.
- During the 2004 to 2010 timeframe, the state adopted a primary seat belt law – this allows law enforcement to stop and ticket drivers if they are not wearing a safety belt. Minnesota's seat belt law is a primary offense, meaning drivers and passengers in all seating positions must be buckled up or in the correct child restraint or law enforcement will stop and ticket unbelted drivers or passengers – including those in the back seats.
- Minnesota occupant restraint usage rate is 95% (June, 2013) – the highest in Minnesota history. Nationally, seat belt use is much lower (86% in 2012).
- A 2014 study sponsored by the Minnesota Department of Public Safety and led by the University of Minnesota Humphrey School of Public Affairs indicate that from June 2009 (when Minnesota's primary law was implemented) through June 2013, there were at least 132 fewer deaths, 434 fewer severe injuries, and 1,270 fewer moderate injuries than expected without a primary seat belt law. For further information, see *Evaluation Update on the Effectiveness of the Minnesota Primary Seatbelt Law* at **www.cts.umn.edu/Research/ProjectDetail.html?id=2014053**.

Infrastructure Focus Area – Intersections

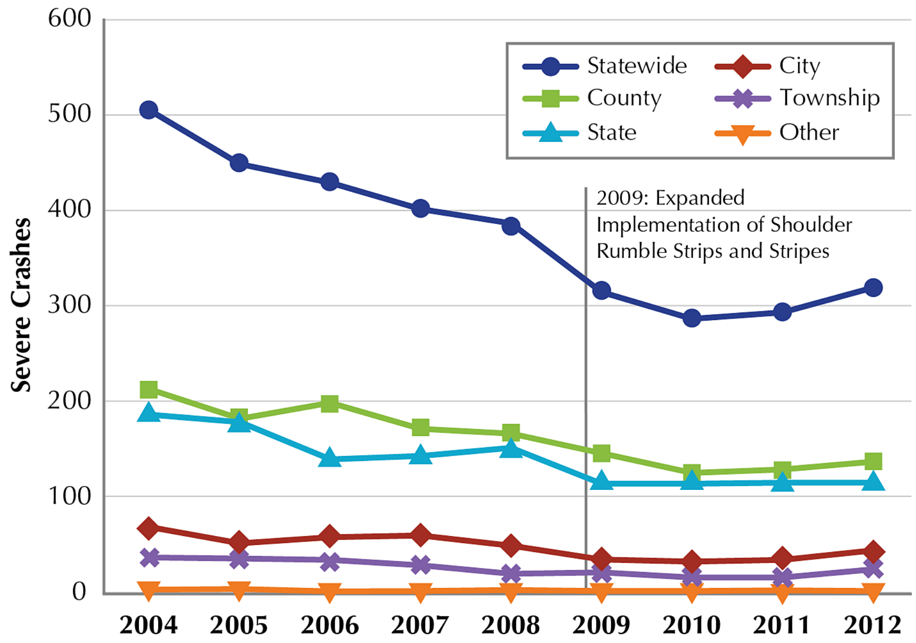


2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- Intersection-related crashes account for nearly 42% of all severe crashes in Minnesota.
- The number of intersection-related crashes fell steadily between 2004 and 2011 and then increased slightly.
- The most frequent type of severe crash at both STOP (55%) and signal controlled (38%) intersections involves a right angle collision.
- In response to the overrepresentation of right angle collisions at intersections, agencies have implemented various intersection safety strategies such as lighting at rural county road intersections, innovative designs that limit access at expressway intersections, and new technology to help law enforcement address red light violations at traffic signals.
- Disaggregated by system, County roadways have the greatest number of intersection-related crashes followed by State highways and then City streets.

Infrastructure Focus Area – Lane Departure



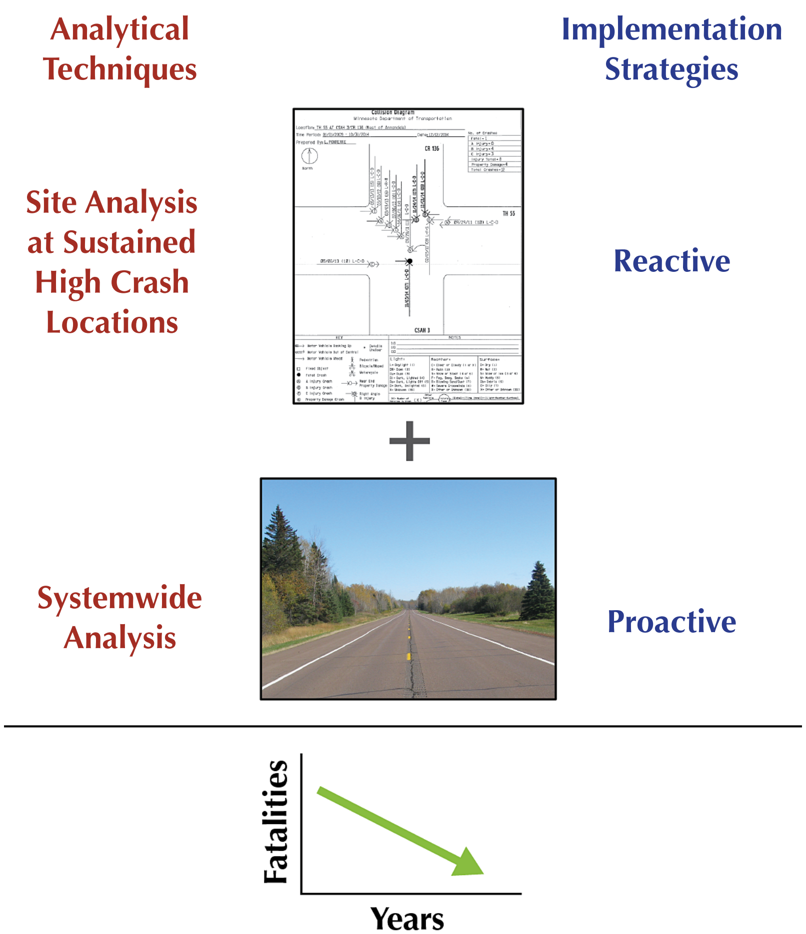
2014-2019 Minnesota Strategic Highway Safety Plan

Highlights

- Lane departure-related crashes account for approximately 45% of all severe crashes in Minnesota.
- The number of lane departure-related crashes fell steadily between 2004 and 2011 and then increased slightly.
- Roadway features that contribute to lane departure crashes include the lack of useable shoulders, steep slopes, and fixed objects in the ditches. One additional feature, the presence of curves, especially those with radii under 1,200 feet, is associated with single vehicle road departure crashes. On the county system more than one-half of these crashes occur along curves and approximately one-third of the state system.
- In response to these crashes, the State and County agencies implemented various lane departure safety strategies such as edgeline and centerline rumble strips and the addition of chevrons along rural horizontal curves.
- Disaggregated by system, County roadways have the greatest number of lane departure-related crashes, followed by State highways.

Comprehensive Safety Improvement Process

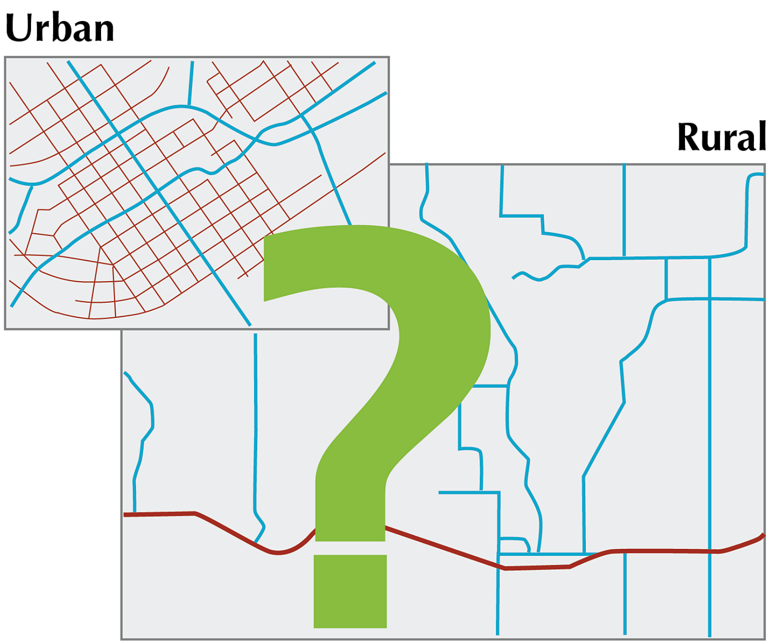
Comprehensive Safety Improvement Process



Highlights

- For the past 30 years, most safety programs have been focused on identifying locations with a high frequency or rate of crashes – Sustained High Crash Locations (SHCLs) – and then reactively implementing safety improvement strategies.
- A location is generally considered to be an SHCL if its severe (fatal and incapacitating injury) crash rate exceeds its severe critical crash rate.
- The result of making SHCLs the highest priority in the safety program was to focus safety investments primarily on urban and suburban signalized intersections – the locations with the highest number of crashes. However, intersections identified as SHCLs do not account for all fatal crashes.
- A review of MnDOT's Trunk Highway System found a total of three intersections that averaged one severe crash per year.
- A new, more systemic analysis of Minnesota's crash data, combined with the adoption of a goal to reduce fatal crashes, has led to a more comprehensive approach to safety programming – a focus on SHCLs in urban areas where there are intersections with high frequencies of crashes and a systems-based approach for rural areas where the total number of severe crashes is high but the actual number of crashes at any given location is very low.

Why Have a Sustained High Crash Location Identification Process?



"Rural" refers to a non–municipal area and cities with a population less than 5,000.

Highlights

- Conducting periodic reviews of your system to identify locations with a sustained high crash frequency supports project development activities and are an integral part of a best practices approach to risk management. Monitoring the safety of your system is good practice and is the industry "norm" against which you will be evaluated.

Project Development

- Crashes are one measurable indicator of how well a system of roadways and traffic control devices is functioning.
- Understanding safety characteristics can assist in the prioritization and development of roadway improvement projects by helping document *Purpose* and *Need*.

Risk Management

- Actively identifying potentially hazardous locations is better than being in the mode of reacting to claims of potentially hazardous locations by the public (or plaintiff's attorneys).
- Knowledge (actual or constructive) of hazardous conditions is one of the prerequisites for proving government agency negligence in tort cases resulting from motor vehicle crashes.
- All crash analysis performed as part of a safety improvement program is *not subject to discovery* in tort lawsuits.

Data Systems

- In order to be able to develop countermeasures to mitigate the effects of crashes, agencies need a monitoring system to identify crash locations and the key characteristics and contributing factors associated with the crashes. The MnDOT "Toolkit" provides all of the necessary crash, roadway and traffic control characteristics for segments and intersections on the Trunk Highway system. MnCMAT plus local agency inventories would provide the data necessary to support site analyses at locations identified as having sustained high crash frequency or rate of crashes along county roads and city streets.

Alternative Methods for Identifying Potentially Hazardous Locations

1 **Number of Crashes annually is greater than X crashes per year.**

2 **Crash Rate is greater than Y crashes per million vehicles annually.**

3 **Critical Rate is a statistically adjusted Crash Rate to account for random nature of crashes.**

Highlights

- There are three primary methods for identifying potentially hazardous locations.
- The first method would involve setting an arbitrary threshold value of X crashes per year at any particular location. This method is the simplest approach with the fewest data requirements. However, the selection of the threshold value is subjective and this methodology does not account for variations in traffic volume or roadway design/traffic control characteristics. This method is better than nothing and would be most applicable in systems consisting of similar types of roads with only small variations in traffic volumes.
- The second method consists of computing crash rates and then comparing them to an arbitrarily selected threshold value of Y crashes per unit of exposure (a crash rate).

Advantage:

- Allows comparison of facilities with different traffic volumes.

Disadvantages:

- Subjective selection of the threshold value.
- Requires more data (traffic volumes). Does not account for known variation in crash rates among different types of road designs.
- Does not account for the random nature of crashes.

Conclusion: Limited applicability, better than using crash frequency only.

- The third method involves using a statistical quality control technique called Critical Crash Rate.

Advantage:

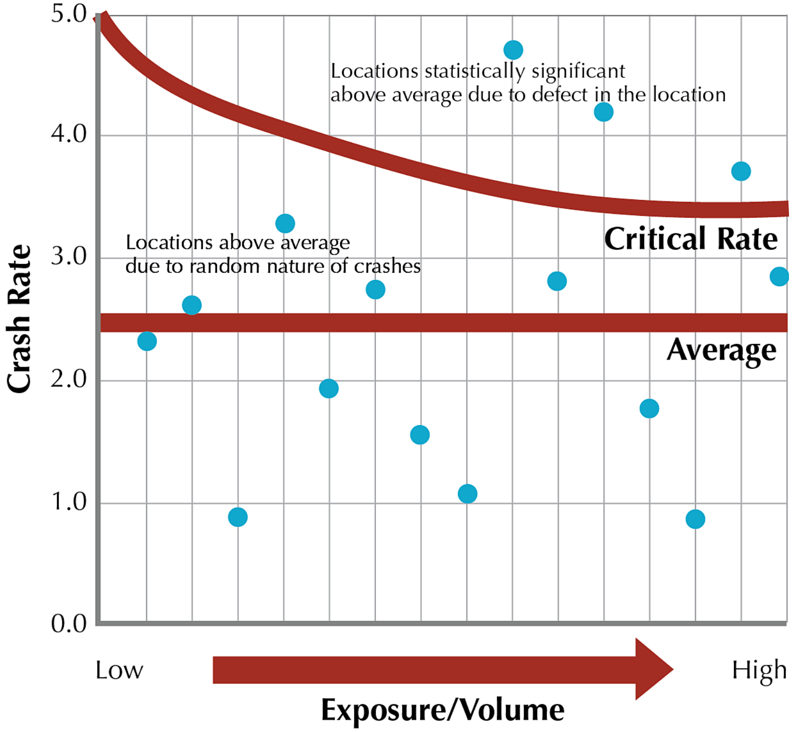
- Only identifies those locations as hazardous if they have a crash rate statistically significantly higher than at similar facilities.

Disadvantage:

- Most data-intensive methodology (volumes and categorical averages).

Conclusion: Of the three methods, critical crash rate is the most accurate and statistically reliable method for identifying hazardous locations.

Effect of Random Distribution of Crashes



Highlights

The Concept of Critical Crash Rate

- The technique that uses the critical crash rate is considered to be a highly effective technique for identifying hazardous locations.
- The critical crash rate accounts for the key variables that affect safety, including:
  - The design of the facility
  - The type of intersection control
  - The amount of exposure
  - The random nature of crashes
- The concept suggests that any sample or category of intersections or roadway segments can be divided into three basic parts:
  - Locations with a crash rate below the categorical average: These locations are considered to be *SAFE* because of the low frequency of crashes and can be eliminated from further review.
  - Locations with a crash rate above the categorical average, but below the critical rate: These locations are considered to be *SAFE* because there is a very high probability (90-95%) that the higher than average crash rate is due to the random nature of crashes.
  - Locations with a crash rate above the critical rate: These locations are considered to be *UNSAFE* and in need of further review because there is a high probability (90-95%) that conditions at the site are contributing to the higher crash rate.
- The other advantage of using the critical crash rate is that it helps screen out 90% of the locations that do not have a problem and focuses an agency's attention and resources on the limited number of locations that do have a documented problem (as opposed to a perceived problem).
- The relationship between the critical crash rate and the level of vehicular exposure should be noted. As the volume of traffic at the intersection or segment being studied increases, the difference between the system average and the critical rate diminishes.

Calculating Crash Rates

MEV Million Entering Vehicles
MVM Million Vehicle Miles
ADT Average Daily Traffic on each leg entering an intersection or the daily two-way volume on a segment of roadway

Intersection Rate:

$$\text{Rate per MEV} = \frac{(\text{number of crashes}) \times (1 \text{ million})}{(\text{number of years}) \times (\text{ADT}) \times (365)}$$

Segment Rate:

$$\text{Rate per MVM} = \frac{(\text{number of crashes}) \times (1 \text{ million})}{(\text{segment length}) \times (\text{number of years}) \times (\text{ADT}) \times (365)}$$

Severity Rate:

$$\text{Rate per MVM} = \frac{((5 \times \text{number of Ks}) + (4 \times \text{no. As}) + (3 \times \text{no. Bs}) + (2 \times \text{no. Cs}) + \text{no. PDOs}) \times (1 \text{ million})}{(\text{number of years}) \times (\text{ADT}) \times (365)}$$

Critical Rate:

$$R_c = R_a + K \times (R_a/m)^{1/2} + 0.5/m$$

Level of Confidence	0.995	0.950	0.900
K	2.576	1.645	1.282

R_c = Critical Crash Rate
– for intersections: crashes per MEV
– for segments: crashes per MVM
R_a = System Wide Average Crash Rate by Intersection or Highway Type
m = Vehicle Exposure During Study Period
– for intersections: years x ADT x (365/1 million)
– for segments: length x years x ADT x (365/1 million)
k = Constant based on Level of Confidence

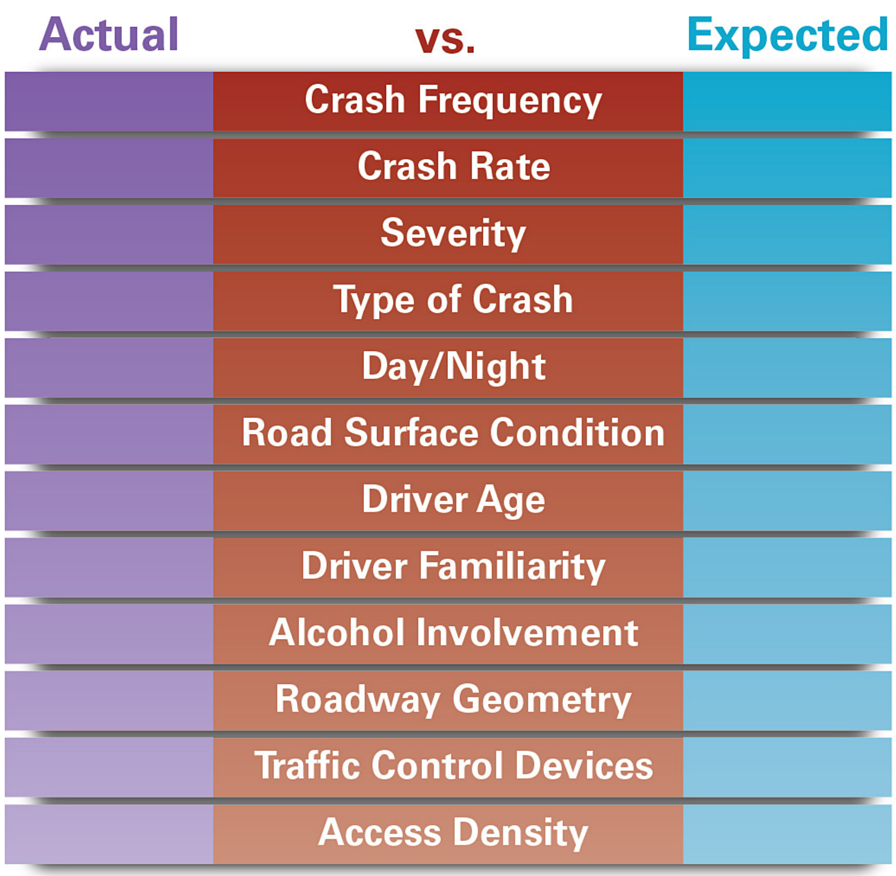
Safety analysts should be aware of the effect sample size has on the overall level of credibility assigned to the results of their studies. As the number of crashes in the study increases, the percent change needed to be statistically reliable diminishes.

Number of Crashes (Sample Size)	10	30	65	125	200
Percent Change (95% Level)	50%	30%	20%	15%	12%

Highlights

- The number of crashes at any location is usually a function of exposure. As the number of vehicles entering an intersection or the vehicle miles of travel along a roadway segment increase, the number of crashes typically increase.
- The use of crash rates (crash frequency per some measure of exposure) accounts for this variability and allows for comparing locations with similar designs but different volumes.
- Intersection crash rates are expressed as the number of crashes per million entering vehicles.
- Segment crash rates are expressed as the number of crashes per million vehicle miles (of travel).
- The critical crash rate is calculated by adjusting the systemwide categorical average based on the amount of exposure and desired statistical level of confidence.
- The difference between the systemwide categorical average and the critical rate increases as the volume decreases.
- When computing the critical crash rate, the term m (vehicle exposure) is the denominator in the equations used in the calculation of either the intersection or segment crash rate.
- The same formulas can be used to calculate critical fatality or injury rates, or the rate at which a particular type of crash is occurring.
- A good rule of thumb is to use 3 to 5 years of crash data when available. More data are almost always useful, but increases the concern about changed conditions. Using only 1 or 2 years of data presents concerns about sample size and statistical reliability.
- Safety analysts should be aware of the effect sample size has on the overall level of credibility assigned to the results of their studies. As the number of crashes in the study increases, the percent change needed to be statistically reliable diminishes.

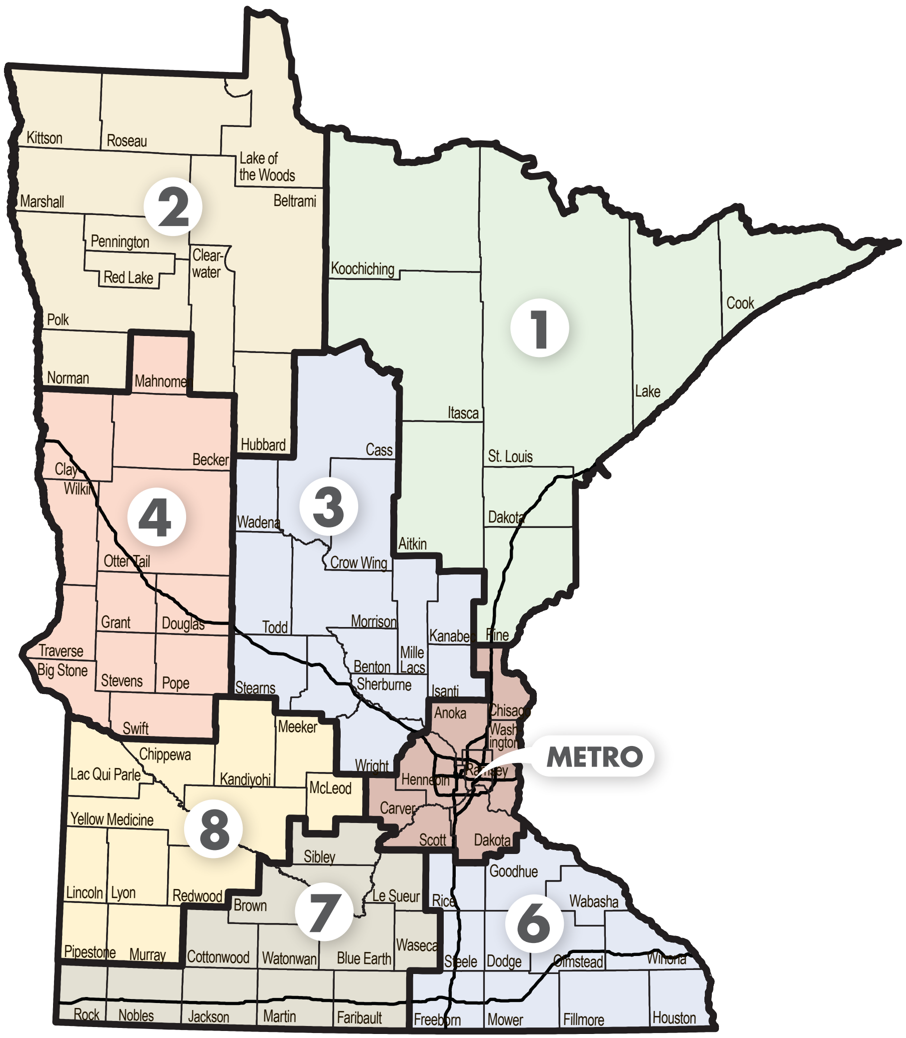
Supplemental Analysis – More Detailed Record Review



Highlights

- After identifying hazardous locations, the next step is to conduct supplemental analyses in order to better understand the nature of the problem and to help develop appropriate mitigative strategies.
- A more detailed understanding of the contributing factors is necessary to develop countermeasures because there is currently no expert system in place that allows mapping from a high crash rate to the base safety solution. Traffic engineers need to know more about the particular problems at specific locations because our "Toolkit" is far less developed than other areas of roadway engineering.
- The supplemental analysis of crash data involves comparing ACTUAL crash characteristics to EXPECTED characteristics and then evaluating for differences. These differences document crash causation factors that help identify effective countermeasures.
- It is important to remember that roads that are similar in design, with similar volumes, will operate in a similar manner and will probably have similar crash characteristics.
- MnDOT's "Toolkit" and the information provided in Section A of this handbook provide insight about expected conditions along Minnesota's roadways.
- The Highway Safety Manual (see page C-8) can contribute to a detailed analysis by documenting Safety Performance Functions (SPFs) that compute the expected crash frequency for a variety of roadway cross-sections and intersection types.

MnDOT's Identification of At-Risk Trunk Highway Facilities



Highlights

- MnDOT uses a number of techniques to identify potentially hazardous locations, including critical crash rate, crash frequency, crash severity, and crash cost.
- MnDOT publishes an annual Top 200 list of high-crash-rate intersections along the state's 12,000-mile trunk highway system on an annual basis.
- The list ranks intersections by crash cost, frequency, severity, and rate.
- Intersections on the list generally have the following characteristics:
  - Crash frequencies between 1 and 63 per year.
  - Crash rates between 0.2 and 5.7 crashes per million entering vehicles.
  - Crash costs between \$0.26 million and \$1.2 million per year.
- Listed intersections are overwhelmingly signalized (70%) and in urban areas (69%).
- In general, this list does NOT adequately identify intersections with safety deficiencies in rural areas.
- This approach also does not necessarily identify locations with fatal crashes (fewer than 10% of fatal crashes in Minnesota occurred at intersections in the Top 200 list).
- The key point is that a high crash rate analysis should continue to be a necessary part of a comprehensive safety program, but a systemic evaluation should also be performed.
- A review of MnDOT's Trunk Highway system found a total of three intersections that averaged one severe crash per year and the analysis conducted on the county system (as part of the County Road Safety Plans) looked at over 13,000 rural intersection and no intersection averaged one severe crash per year.

Systemic Analysis – State Highways

Crash Summary by Facility Types – Greater Minnesota Districts

Facility Type			Miles	Crashes: Fatal	Crashes: Serious Injury	Crash Rate	Severity Rate	Fatal Rate	Crash Density
Rural	Freeway		742.8	62	141	0.54	0.61	0.27	3.39
Rural	4-Lane Expressway		735.8	99	169	0.65	1.12	0.66	2.68
Rural	4-Lane Undivided		27.5	2	3	0.63	0.80	0.53	1.73
Rural	4-Lane Divided Conventional (Non-Expressway)		103.6	13	27	0.82	1.40	0.67	3.06
Rural	2-Lane	ADT < 1,500	3,953.2	99	171	0.64	2.59	1.50	0.21
Rural	2-Lane	1,500 ≤ ADT < 5,000	3,744.3	184	299	0.54	1.56	0.96	0.56
Rural	2-Lane	5,000 ≤ ADT < 8,000	556.4	54	96	0.59	1.51	0.85	1.35
Rural	2-Lane	ADT ≥ 8,000	126.4	17	30	0.56	1.18	0.67	2.23
Rural	**Sub Total**		**9,990**	**530**	**936**				
Urban	Freeway		20.6	4	16	1.33	1.00	0.25	20.73
Urban	4-Lane Expressway		44.1	7	30	2.16	2.35	0.55	12.52
Urban	4-Lane Undivided		42.7	4	18	3.05	2.06	0.46	12.46
Urban	4-Lane Divided Conventional (Non-Expressway)		55.3	8	31	2.43	1.80	0.47	15.12
Urban	3-Lane		26.3	6	4	2.02	0.87	1.31	7.05
Urban	5-Lane		16.9	0	8	2.39	1.84	0.00	12.34
Urban	2-Lane	ADT < 1,500	77.2	5	10	1.91	7.74	3.87	0.64
Urban	2-Lane	1,500 ≤ ADT < 5,000	266.9	12	25	1.35	1.78	0.85	1.43
Urban	2-Lane	5,000 ≤ ADT < 8,000	96.5	4	33	1.80	2.95	0.36	4.17
Urban	2-Lane	ADT ≥ 8,000	51.7	2	24	2.29	2.41	0.20	8.80
Urban	**Sub Total**		**698**	**52**	**199**				

Crash Summary by Facility Types – Metro District

Facility Type			Miles	Crashes: Fatal	Crashes: Serious Injury	Crash Rate	Severity Rate	Fatal Rate	Crash Density
Rural	Freeway		122	22	24	0.6	0.9	0.5	11.1
Rural	4-Lane Expressway		111	17	65	1.0	1.5	0.7	10.3
Rural	4-Lane Undivided		0	0	0	2.5	3.1	0.0	14.8
Rural	4-Lane Divided Conventional (Non expressway)		1	0	0	1.3	2.0	0.0	9.2
Rural	2-Lane	ADT < 1,500	13	0	2	0.0	0.0	0.0	0.5
Rural	2-Lane	1,500 ≤ ADT < 5,000	89	5	8	1.0	1.5	2.0	1.3
Rural	2-Lane	5,000 ≤ ADT < 8,000	98	8	18	1.2	2.0	1.8	2.7
Rural	2-Lane	ADT ≥ 8,000	137	17	33	1.3	2.0	1.2	6.9
Rural	**Sub Total**		**571**	**69**	**150**				
Urban	Freeway		267	43	128	1.2	1.6	0.2	41.7
Urban	4-Lane Expressway		124	17	81	1.9	2.7	0.5	23.9
Urban	4-Lane Undivided		20	2	25	5.8	7.8	0.7	41.3
Urban	4-Lane Divided Conventional (Non expressway)		21	3	19	5.0	6.8	0.9	38.6
Urban	3-Lane		9	0	2	3.1	4.3	0.0	16.8
Urban	5-Lane		2	0	3	5.6	8.8	0.0	52.4
Urban	2-Lane	ADT < 1,500	1	0	0	4.0	6.3	0.0	2.1
Urban	2-Lane	1,500 ≤ ADT < 5,000	9	0	0	2.8	3.9	0.0	3.7
Urban	2-Lane	5,000 ≤ ADT < 8,000	26	2	2	2.3	3.3	1.6	5.5
Urban	2-Lane	ADT ≥ 8,000	54	6	20	3.0	4.2	1.1	15.6
Urban	**Sub Total**		**533**	**73**	**280**				

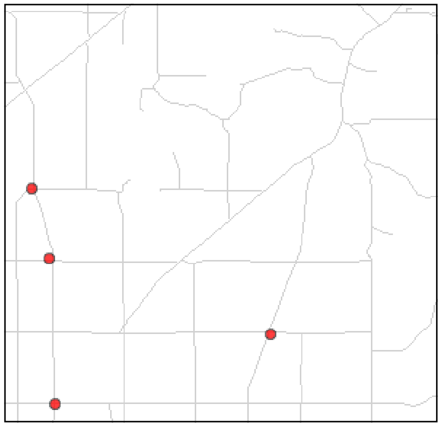
2013 MnDOT Crash Data Toolkit, 2009-2013

Highlights

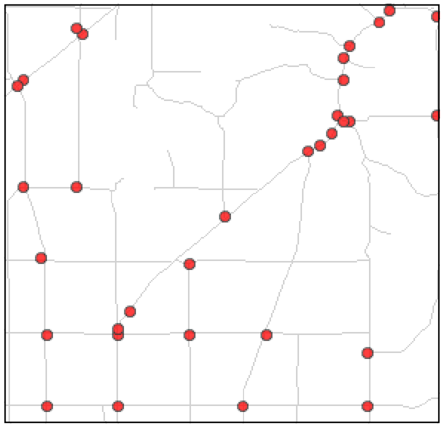
- Historically, the absence of sustained high crash locations in a system of roads was interpreted to mean that there were no safety deficiencies and that there were no opportunities to effectively make investments to reduce crashes.
- However, a new interpretation of the crash data by the FHWA and an increasing number of state departments of transportation suggests that neither assumption is correct.
- A review of Minnesota's crash data, conducted as part of the SHSP, provides several insights in support of a systemic approach for addressing safety deficiencies.
- On the state's highway system, the facility types that present the greatest opportunity to reduce fatal crashes (based on the total number of fatal crashes) are rural two-lane roads (50%) and freeways (22%). However, until recently there have been few projects on these facilities because the process of filtering the data failed to identify any sustained high crash locations.
- Further analysis of these priority facilities shows that neither the overall crash rate nor the fatality rate is at all unusual, but the pool of fatal crashes susceptible to correction is still large and represents the greatest opportunity for reduction: addressing road departure crashes on rural two–lane roads and cross-median crashes on freeways.
- The final point in support of a systemic approach to address safety in rural areas is the very low density of crashes along rural two-lane highways – 61% of fatal crashes occur on the 87% of the system that averages less than one crash per mile per year.

Note: Crash rate is crashes per million vehicle miles; fatality rate is fatal crashes per 100 million vehicle miles.

Systemic Analysis – County Highways



Intersections with multiple severe crashes in 5-year period.



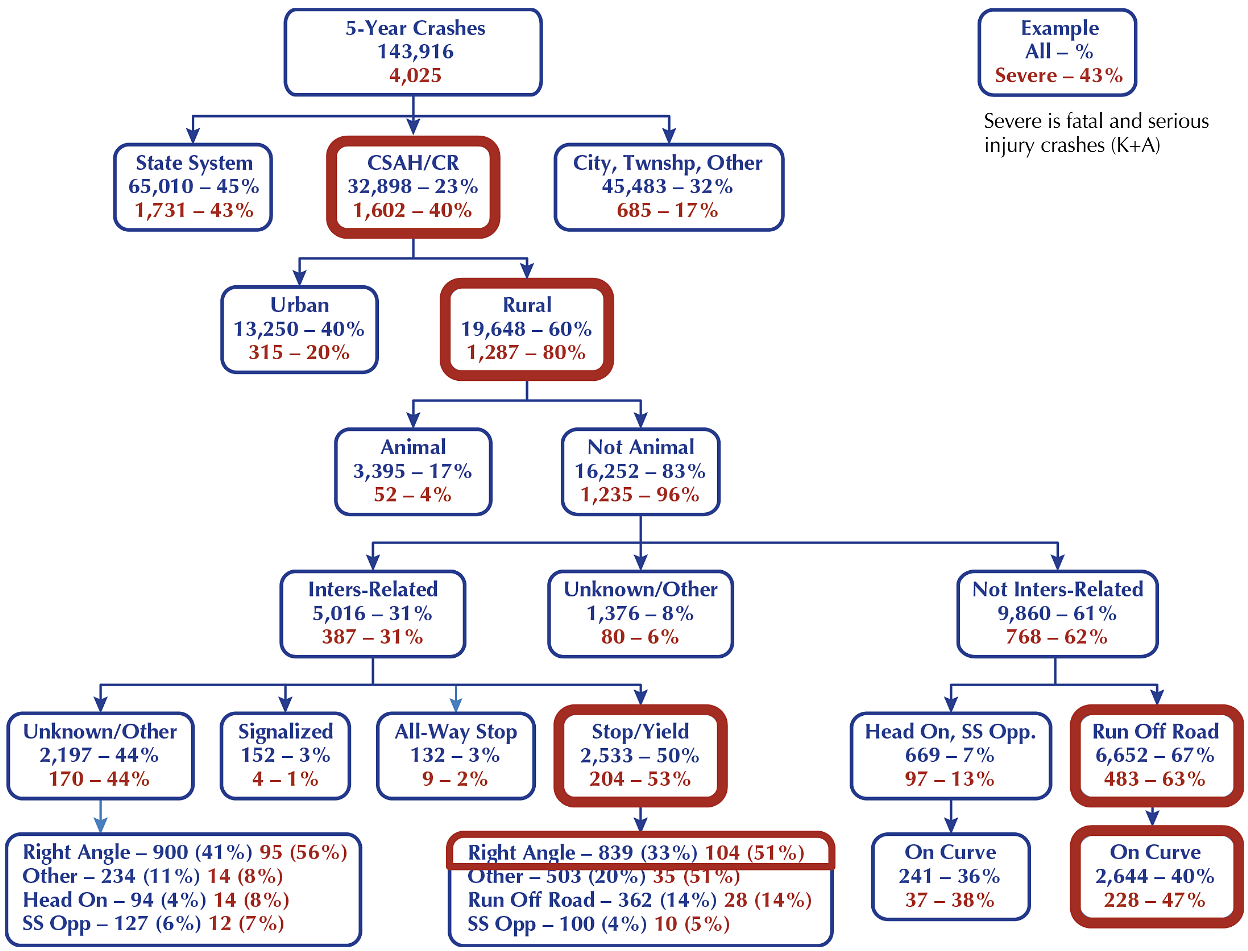
Intersections considered high priority based on risk assessment.

Highlights

- Historically, the primary candidates for safety investment were locations identified as having a high frequency of crashes compared to other similar intersections or roadway segments (frequently referred to as sustained high crash locations or SHCLs).
- Over time, it was recognized that this approach had two district disadvantages:
  - First, this approach made highway agencies entirely reactive (agency staff had to try to respond to the phone call that asked – "How many people have to die before you do something?")
  - Second, in 2005 FHWA required states to base their safety programs on severe crashes (fatal + serious injury) instead of all severities. Subsequent analysis found that there are only a few locations in Minnesota where multiple severe crashes occur and virtually none along local systems.
- In response, MnDOT added a "systemic" component to its Highway Improvement Program to complement the historic reactive component.
- The systemic approach uses crash surrogates – roadway and traffic characteristics that appear to be overrepresented at the locations around Minnesota where serious crashes occur – to identify at-risk locations that are candidates for safety investment.
- The systemic approach was used to prepare safety plans for all 87 counties in Minnesota. The analyses of each county's system of roads identified the types of crashes that represent the greatest opportunity for reductions, the short list of highly effective strategies and a prioritized list of candidate locations for safety investment based on the pretense of roadway and traffic characteristics that were associated with locations with severe crashes. The outcome of the effort was the identification of over 17,000 projects with an estimated implementation cost of approximately $246 M. It should be noted that not a single location identified as being at-risk along the county system averaged one severe crash per year and would not have been identified as a high-crash location.

Systemic Analysis – County Highway Crash Data for Greater Minnesota

ATP's 1, 2, 3, 4, 6, 7, and 8 – NO Metro



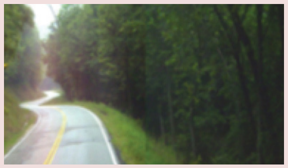
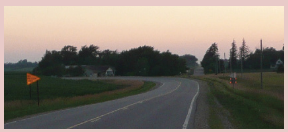
Minnesota Crash Mapping Analysis Tool, 2009-2013

Highlights

Greater Minnesota Crash Data Overview

- The "systemic" approach has proved to be particularly effective at identifying at-risk locations for safety investment along Minnesota's county highway system.
- In greater Minnesota, the number of severe crashes on the county roadway system is virtually identical to the number on the state system (approximately 500 severe crashes/year). However, the two most common types – road departure and right angle crashes – are scattered across almost 27,000 miles of paved roads and 13,000 intersections. This results in average densities of 0.007 per mile and 0.006 per intersection. In addition, more than 90% of these facilities had NO severe crashes (over 5 years) and NONE averaged one severe crash per year.
- The traditional reactive-based analysis would have concluded that there are NO candidates for safety investment. The risk-based systemic analysis came to a different conclusion and identified approximately $232 M of road edge, curve delineation, and intersection safety improvements based on the probability of a crash occurring at the location with multiple risk factors present.

Systemic Analysis – County Highway Assessment

Roadway and Traffic Characteristics		
Segments		– Density of Road Departure – Traffic Volume – Critical Curve Radius Density – Access Density – Edge Risk Assessment
Curves		– ADT Range – Radius Range – Severe Crash on Curve – Intersection on Curve
Intersections		– Skewed Approaches – On/Near Curve – Volume – Proximity to Railroad Crossing – Proximity to Last STOP Sign – Intersection-Related Crashes – Commercial Development in Quadrant

Otter Tail County
Rural Segment Prioritization

Rank	Corridor	Route	#	Start	End	Length	ADT	ADT Range	RD Density	Access Density	Curve Critical Radius Density	Edge Risk	Totals	Tiebreakers Edge Risk	Tiebreakers RD Density
1	34.01	CSAH	34	CSAH 35	PERHAM CORP LMTS	6.8	1,148	★	★	★	★	★	★★★★★	3	0.32
2	4.04	CSAH	4	VERGAS CORP LMTS	BECKER COUNTY LINE	4.7	1,170	★	★	★	★	★	★★★★★	3	0.13
3	35.07	CSAH	35	CSAH 41	DENT CORP LMTS	9.3	684	★	★	★	★	★	★★★★★	2	0.17
4	9.03	CSAH	9	MNTH 34	BECKER COUNTY LINE	5.2	863	★	★	★	★	★	★★★★★	2	0.15
5	31.02	CSAH	31	USTH 59	CSAH 20	2.9	558		★	★	★	★	★★★★	3	0.21
6	64.01	CSAH	64	MNTH 78	DOUGLAS COUNTY LIN	0.6	350		★	★	★	★	★★★★	2	0.67
7	35.05	CSAH	35	UNDERWOOD CORP LM	CSAH 1	6	1,115	★	★		★	★	★★★★	2	0.43
8	5.03	CSAH	5	CLITHERALL CORP LMT	CSAH 16	4.7	650	★	★		★	★	★★★★	2	0.21
9	35.01	CSAH	35	USTH 59	DALTON CORP LMTS	5.8	602	★	★		★	★	★★★★	2	0.21
10	3.01	CSAH	3	CSAH 10	CSAH 24	8.4	596		★	★	★	★	★★★★	2	0.14
11	33.01	CSAH	33	CSAH 35	MNTH 210	8.5	251		★	★	★	★	★★★★	2	0.12
12	83.02	CSAH	83	BATTLE LAKE CORP LM	CSAH 1	8.5	388		★	★	★	★	★★★★	2	0.12
13	122.02	CNTY	122	UNDERWOOD CORP LM	CSAH 83	5.4	[illegible]	★	★		★	★	★★★★	2	0.11
14	3.02	CSAH	3	CSAH 24	USTH 59	7.5	[illegible]	★	★		★	★	★★★★	2	0.08
15	20.01	CSAH	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		★★★★	1	0.20
16	111.02	CNTY	111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		★★★★	1	0.18
17	4.02	CSAH	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	3	0.29
18	31.01	CSAH	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	3	0.08
19	67.03	CSAH	67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	3	0.06
20	35.03	CSAH	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	2	0.14
21	24.05	CSAH	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	2	0.13
22	56.02	CSAH	56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	2	0.09
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	2	0.09
24	[illegible]	CSAH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	★	★★★	2	0.08
183	69.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							1	0.00
184	76.01	CSAH	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							1	0.00
185	80.01	CSAH	80	[illegible]	[illegible]	[illegible]	[illegible]							1	0.00
186	88.03	CSAH	88	CSAH 10	[illegible]	[illegible]	[illegible]							1	0.00
187	112.01	CNTY	112	CSAH 15	[illegible]	[illegible]	[illegible]							1	0.00
188	114.01	CNTY	114	WILKIN COUNTY LINE	CSAH 15	[illegible]	[illegible]							1	0.00
189	127.01	CNTY	127	MNTH 108	CSAH 54	[illegible]	[illegible]							1	0.00
190	135.01	CNTY	135	CSAH 52	CSAH 84	6	215							1	0.00
191	136.02	CNTY	136	MNTH 29	CSAH 40	5	65							1	0.00
192	140.01	CNTY	140	CSAH 67	MNTH 29	4.1	113							1	0.00
193	144.01	CNTY	144	CSAH 19	CSAH 75	3	130							1	0.00
							Total Stars --	33	65	84	78	70			
							% That Gets Star --	17%	34%	44%	40%	36%			

Totals

	#	%	Mileage	%
★★★★★	4	2%	26.0	3%
★★★★	12	6%	67.9	7%
★★★	26	13%	138.2	14%
★★	61	32%	303.7	30%
★	62	32%	325.4	32%
	28	15%	142.9	14%
	193	100%	1004.1	100%

Stars

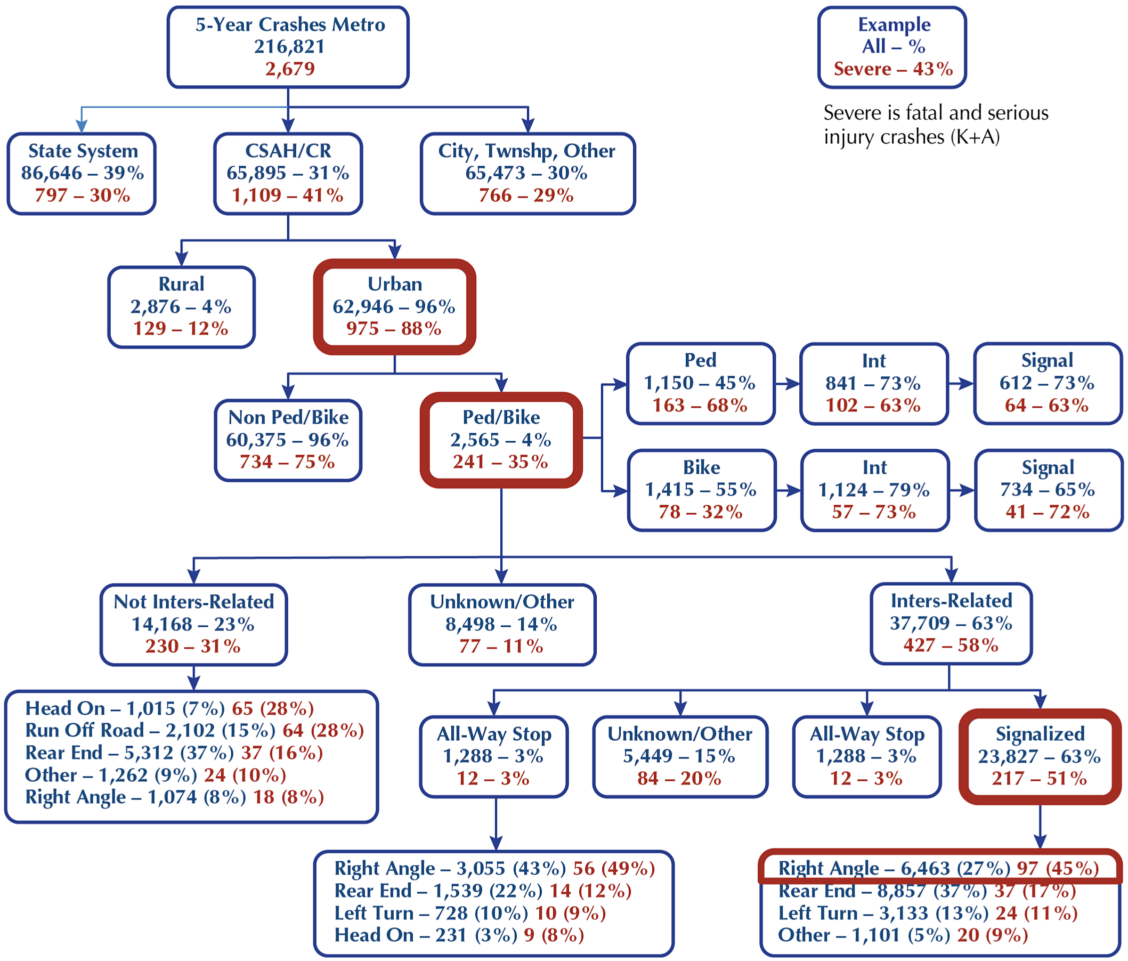
ADT Range - If segment has an ADT in the range of most at risk ADT based on ATP totals. (600 to 1199)
RD Density - If segment has higher road departure density than the county average (0.08).
Access Density If segment has access density than the county average (10.8).
Curve Critical Radius Density - If segment has higher density of curves with critical radius than the county average (0.35).
Edge Risk Assessment - Edge risk of 2 or 3, based on assessment of roadway edge and clear zone

Highlights

Risk Rating Criteria for Rural Paved Roads

- The systemic risk assessment of Minnesota's rural county highways used a variety of roadway and traffic characteristics identified from a review of published safety research and information obtained about the specific locations in Minnesota where severe road departure and right angle crashes occurred.
- The system of paved, secondary roads was analyzed in every county. This analysis used aerial photography, video logs, and MnCMAT to identify the characteristics of each segment, horizontal curve, and intersection.
- The results of the analysis included prioritized listings (based on the number of risk factors present) of segments, curves, and intersections for every county. The priority lists typically identified approximately 25% to 30% of each county's facilities of being at-risk and therefore candidates for safety investment.

Systemic Analysis – County Highway Crash Data for Metro



Minnesota Crash Mapping Analysis Tool, 2009-2013

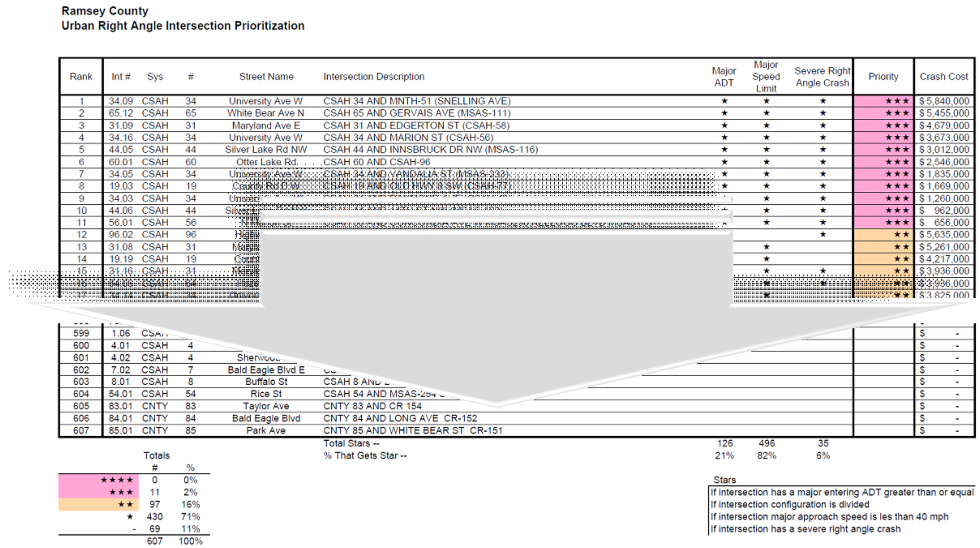
Highlights

Metro County Crash Data Overview

- The systemic approach was also applied to the urban counties in the Minneapolis – St. Paul Metropolitan Area. In these counties, the number of crashes exceeds the number on the State system by almost 45%.
- The most common types of severe crashes include, for segments:
  - Rear-end
  - Sideswipe
  - Head-on
- For intersections the most comment type of severe crashes are:
  - Right angle
  - Pedestrian/bicyclist
- However, the crashes were scattered over almost 1,600 miles of roadway and 2,900 intersections. This results in average densities of 0.05 severe crashes/mile, and 0.01 crashes/intersections. In addition, approximately 90% of the urban fatalities had NO severe crashes and NONE averaged one severe crash per year.
- As was the case in rural areas, the traditional reactive analysis would have concluded that there are NO candidates for safety investment based only on the presence of crashes. The risk-based systemic analysis identified approximately $14M of segment and intersection safety improvements that could be deployed proactively that would prevent the occurrence of the priority crash types.

Systemic Analysis – County Highway Assessment for Metro

Roadway and Traffic Characteristics		
Urban Intersections (Right Angle Crashes)		– Density of Road Departure – Traffic Volume – Critical Curve Radius Density – Access Density – Edge Risk Assessment
Urban Intersections (Pedestrian/ Bicycle Crashes)		– ADT Range – Radius Range – Severe Crash on Curve – Intersection on Curve



Ramsey County
Urban Right Angle Intersection Prioritization

Rank	Int #	Sys	#	Street Name	Intersection Description	Major ADT	Major Speed Limit	Severe Right Angle Crash	Priority	Crash Cost
1	34.09	CSAH	34	University Ave W	CSAH 34 AND MNTH-51 (SNELLING AVE)	★	★	★	★★★	$ 5,840,000
2	65.12	CSAH	65	White Bear Ave N	CSAH 65 AND GERVAIS AVE (MSAS-111)	★	★	★	★★★	$ 5,455,000
3	31.09	CSAH	31	Maryland Ave E	CSAH 31 AND EDGERTON ST (CSAH-58)	★	★	★	★★★	$ 4,679,000
4	34.16	CSAH	34	University Ave W	CSAH 34 AND MARION ST (CSAH-56)	★	★	★	★★★	$ 3,673,000
5	44.05	CSAH	44	Silver Lake Rd NW	CSAH 44 AND INNSBRUCK DR NW (MSAS-116)	★	★	★	★★★	$ 3,012,000
6	60.01	CSAH	60	Otter Lake Rd.	CSAH 60 AND CSAH-96	★	★	★	★★★	$ 2,546,000
7	34.05	CSAH	34	University Ave W	CSAH 34 AND VANDALIA ST (MSAS-233)	★	★	★	★★★	$ 1,835,000
8	19.03	CSAH	19	[illegible]	[illegible]	★	★	★	★★★	$ 1,669,000
9	34.03	CSAH	34	Univer[illegible]	[illegible]		★	★	★★★	$ 1,260,000
10	44.06	CSAH	44	Silver[illegible]	[illegible]		★	★	★★★	$ 962,000
11	56.01	CSAH	56	[illegible]	[illegible]		★	★	★★★	$ 656,000
12	96.02	CSAH	96	[illegible]	[illegible]			★	★★	$ 5,635,000
13	31.08	CSAH	31	[illegible]	[illegible]		★		★★	$ 5,261,000
14	19.19	CSAH	19	[illegible]	[illegible]		★		★★	$ 4,217,000
15	31.16	CSAH	31	[illegible]	[illegible]		★	★	★★	$ 3,936,000
16	[illegible]	CSAH	[illegible]	[illegible]	[illegible]		★	★	★★	$ 3,936,000
17	[illegible]	CSAH	[illegible]	[illegible]	[illegible]		★		★★	$ 3,825,000
599	1.06	CSA[illegible]								$ -
600	4.01	CSAH	4							$ -
601	4.02	CSAH	4	Sherwoo[illegible]						$ -
602	7.02	CSAH	7	Bald Eagle Blvd E	[illegible]					$ -
603	8.01	CSAH	8	Buffalo St	CSAH 8 AND [illegible]					$ -
604	54.01	CSAH	54	Rice St	CSAH 54 AND MSAS-254 [illegible]					$ -
605	83.01	CNTY	83	Taylor Ave	CNTY 83 AND CR 154					$ -
606	84.01	CNTY	84	Bald Eagle Blvd	CNTY 84 AND LONG AVE CR-152					$ -
607	85.01	CNTY	85	Park Ave	CNTY 85 AND WHITE BEAR ST CR-151					$ -
					Total Stars --	126	496	35		
					% That Gets Star --	21%	82%	6%		

Totals

	#	%
★★★★	0	0%
★★★	11	2%
★★	97	16%
★	430	71%
-	69	11%
	607	100%

Stars
If intersection has a major entering ADT greater than or equal
If intersection configuration is divided
If intersection major approach speed is les than 40 mph
If intersection has a severe right angle crash

Highlights

Risk Assessment Findings – Urban Intersection

- The systemic risk assessment of the urban county highways identified the roadway and traffic characteristics that were common to the locations where the priority crash types occurred: right angle and ped/bike crashes. All of the urban county highways were then evaluated using aerial photography, video logs, and MnCMAT for presence of these features.
- The result of the analysis included prioritized listings of segments and intersections for every county. As was the case with the rural counties, the priority lists for the urban counties typically identified approximately 25% to 30% of each county's facilities of being at risk and candidates for safety investment.

Implementation Guidance for State Highways

GREATER MINNESOTA DISTRICTS

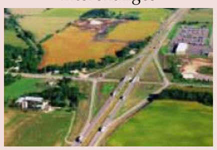
METRO DISTRICT

Reactive → Proactive

GOAL FOR METRO DISTRICT

High-Cost Improvements

Interchanges



Roundabouts

Road Reconstruction

After

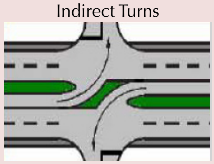
Before

Moderate-Cost Intersection Improvements

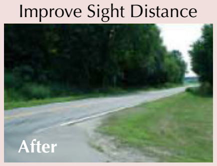
Improve Traffic Signal Operations

Accel/Decel Lanes

Indirect Turns



Improve Sight Distance



After

Before

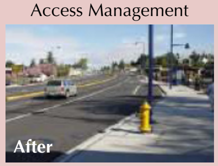
50/50 GOAL

Corridor Management and Technology Improvements

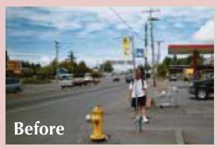
Employ ITS Technologies

Elec. Speed Enforcement in School Zones

Access Management



After



Before

Road Safety Audit

GOAL FOR GREATER MINNESOTA DISTRICTS

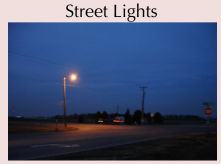
Low-Cost Intersection Improvements

Red Light Enforcement

Turn Lane Modifications

Channelization

Street Lights



Enhance Traffic Signs and Markings

Curb Extensions

Road Departure Improvements

Edge Treatments

Enhanced Del. of Curves

Safety Edge

Paved Shoulders Rumble Strips/Stripes

Cable Median Barrier

Upgrade Roadside Hardware

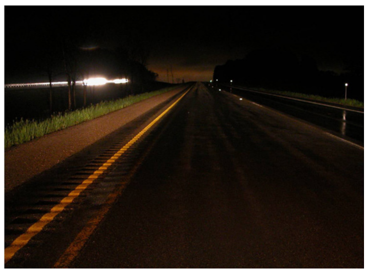
Highlights

- As part of the SHSP, MnDOT developed implementation guidance for the districts.
- The goal for districts in Greater Minnesota is to have a safety program that is primarily focused on proactively deploying (relatively) low-cost safety strategies broadly across their systems of rural two-lane roads and freeways.
- The goal for the Metropolitan District is to base its safety program primarily on deploying generally higher cost safety strategies at its sustained high crash locations, while reserving a fraction of its resources for widely deploying low-cost new technologies or innovations across the system.

Implementation Guidance for County Highways

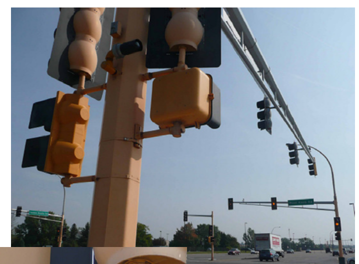
Street Lighting

Dynamic Warning Signs



Rumble Strips

Countdown Timers and Advanced Pedestrian Intervals

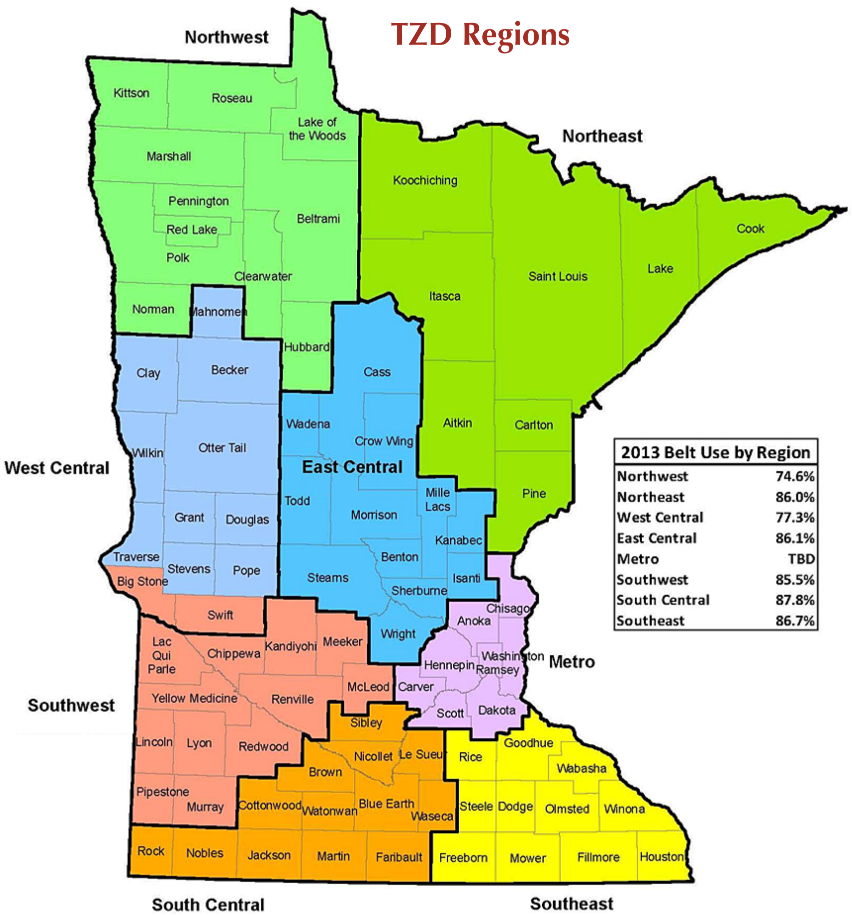


Red-Light Confirmation Lights

Highlights

- The primary objective of the safety analysis conducted as part of the county roadway safety plans was to identify the primary causes of severe crashes and to conduct a prioritization exercise linking at-risk locations with a shortlist of high priority safety strategies – the identification of safety projects that are candidates for funding through the state's highway safety improvement program.
- The review of county crash data found no sustained high crash locations on the county system, but did find a pool of life-changing crashes (fatal + severe injury) that would be susceptible to correction.
- The analysis found the most frequent types of severe crashes in rural counties were road departure crashes along segments and horizontal curves, as well as right angle crashes at Thru/STOP controlled intersections. In the urban counties the most frequent severe crashes were right angle and pedestrian/bicycle crashes at signalized intersections and rear-end in segments.
- The process ultimately identified the following:
    - 16,500 rural road edge, curve delineation, and intersection improvement projects valued at more than $232 M.
    - 660 urban signalized intersection and roadway segment improvements valued at approximately $14 M.

Safety Planning at the Local Level



2013 Belt Use by Region	
Northwest	74.6%
Northeast	86.0%
West Central	77.3%
East Central	86.1%
Metro	TBD
Southwest	85.5%
South Central	87.8%
Southeast	86.7%

Find your local TZD coordinator:
www.minnesotatzd.org/whatistzd/mntzd/contact/

Highlights

- **Minnesota Toward Zero Deaths** is an interdisciplinary partnership which began in 2003 with the Department of Health, Transportation, and Public Safety.
- Our mission is to create a culture for which traffic fatalities and serious injuries are no longer acceptable through the integrated application of **education**, **engineering**, **enforcement**, and **emergency medical and trauma services**. These efforts will be driven by data, best practices, and research.

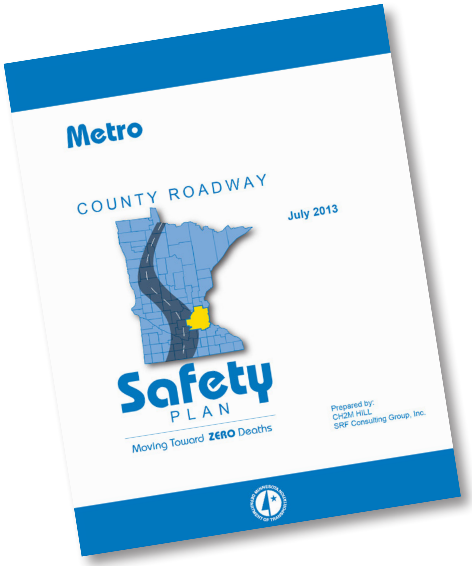
Success

- Interdisciplinary partnership, groundwork, legwork, teamwork, educate on other "E"s to benefit education of all traffic safety.
- Traffic Safety coalitions: www.minnesotatzd.org/initiatives/saferoads/coalition/
- Statewide goals of traffic safety coalitions:
  - Coalitions can include individuals as well as representatives of other organizations, such as police departments or emergency services providers.
  - Coalitions are often more effective than individuals working alone - or even different organizations working independently.
  - Coalitions can develop stronger public support for an issue by increasing visibility and public awareness.
  - Working together is the foundation of the Toward Zero Deaths program.

Public Service

- Media
- Workplace policy and implementation
- Parent component to driver's education
- High Visibility Campaigns – link to calendar: https://dps.mn.gov/divisions/ots/law-enforcement/Pages/calendar.aspx

Safety Planning at the Local Level



Highlights

- Federal highway legislation requires all states to prepare strategic safety plans, and all of the states have complied.
- National crash data indicate between 15% and 60% of traffic fatalities occur on local roads (the national average is 43%). This clearly indicates the need for the states to engage local road authorities in statewide strategic safety planning efforts.
- In Minnesota, almost 65% of crashes involving serious injuries occur on local roads. MnDOT has supported safety planning at the local level by increasing levels of financial assistance and technical support. The 2015-2016 Highway Safety Improvement Program allocated almost $10 million for 53 projects on the local system (including projects that involve enhancing the edge of rural roads, installing chevrons in curves and adding intersection lighting). All of these projects were identified in plans prepared for counties in Minnesota as part of the MnDOT funded County Roadway Safety Plans.
- The single most important practice to support safety at the local level is for agencies to dedicate a portion of their capital improvement program to implementing low-cost strategies on their system.
- In addition to improvements to roadways, other local safety based practices could include:
    - Initiating/participating in Safe Communities program
    - Initiating/participating in Safe Routes to School program
    - Initiating a fatal crash review process that involves law enforcement and engineering staff plus emergency responders
- Support law enforcement initiatives to reduce speeding, improve seat belt compliance and reducing drinking and driving. An example of a highly effective local law enforcement initiative is the Rice County MOD Squad. A team consisting of Rice County sheriffs, the Minnesota Sate Patrol and local police conducted a high-visibility enforcement campaign to "MOD-ify" unsafe driving behavior. The MOD Squad targeted smaller communities and local festivals and celebrations. In the 10 years prior to the high-visibility enforcement campaign, Rice County averaged 12 alcohol-related fatalities per year. In the first year of the campaign, the number dropped to zero.

Section C

Traffic Safety Tool Box

Traffic Safety Tool Box – Then vs. Now

Highlights

THEN:

- Only a few sources of information about the effectiveness of safety projects were available, none were comprehensive and there were concerns about the statistical reliability of the conclusions because of the analytical techniques that were used. Most of the information available was based on observations of a limited number of locations.

NOW:

- Better and more comprehensive set of references are available:
  - NCHRP Series 500 Reports – Implementation of AASHTO's Strategic Highway Safety Plan: **http://safety.transportation.org/guides.aspx**
  - FHWA's Crash Modification Factor Clearinghouse **www.cmfclearinghouse.org**
  - Highway Safety Manual: **www.highwaysafetymanual.org**

Traffic Safety Tool Box – Then vs. Now

Education

- Older Drivers
- Distracted/Fatigued Drivers
- Motorcycles
- Alcohol

Enforcement

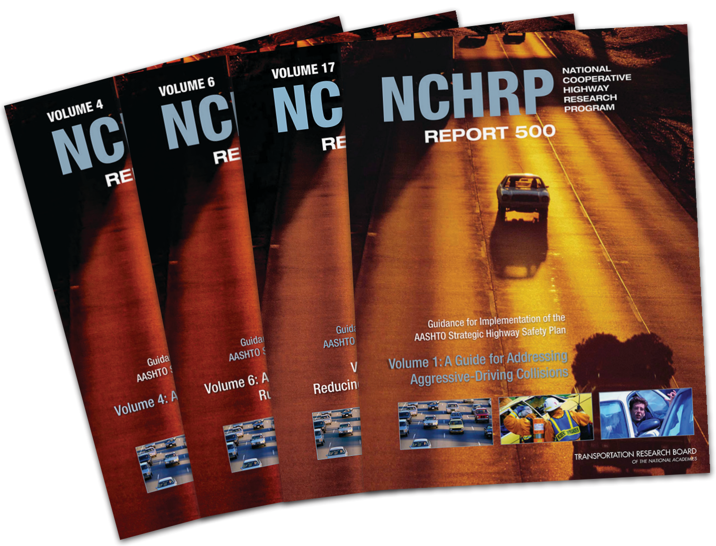
- Aggressive Driving
- Unlicensed/Suspended/Revoked Drivers License
- Unbelted Occupants
- Heavy Trucks

Engineering

- Trees in Hazardous Locations
- Head-On Crashes
- Unsignalized Intersections
- Run-Off-Road Crashes
- Pedestrians
- Horizontal Curves
- Signalized Intersections
- Utility Poles
- Work Zones

Emergency Services

- Rural Emergency Medical Services



Highlights

- The National Cooperative Highway Research Program (NCHRP) developed a series of guides to assist state and local agencies in reducing the number of severe crashes in a number of targeted areas.
- The guides correspond to the 22 safety emphasis areas outlined in AASHTO's Strategic Highway Safety Plan (SHSP).
- Each guide includes a description of the problem and a list of suggested strategies/countermeasures to address the problem.
- The list of strategies in each guide was generated by an expert panel that consisted of both academics and practitioners in order to provide a balance and a focus on feasibility.
- In addition to describing each strategy, supplemental information is provided, including the following:
  - Expected effectiveness (crash reduction factors)
  - Implementation costs
  - Challenges to implementation
  - Organizational and policy issues
  - Designation of each strategy as either Tried, Experimental, or Proven
- **http://safety.transportation.org/guides.aspx**

Effectiveness of Safety Strategies

Proven

Education

- Graduated Drivers Licensing
- Safety Belt Enforcement Campaigns
- DWI Checkpoints

Enforcement

- Street Lights at Rural Intersections
- Access Management
- Roadside Safety Initiatives
- Pave/Widen Shoulders
- Roundabouts
- Exclusive Left Turn Signal Phasing
- Shoulder Rumble Strips

Engineering

- Improved Roadway Alignment
- Cable Median Barrier
- Removing Unwarranted Traffic Signals
- Removing Trees in Hazardous Locations
- Pedestrian Crosswalks, Sidewalks, and Refuge Islands
- Left Turn Lanes on Urban Arterial

Tried

Engineering

- Rumble Strips (on the approach to intersections)
- Neighborhood Traffic Control (Traffic Calming)
- Overhead Red/Yellow Flashers
- Increased Levels of Intersection Traffic Control
- Indirect Left Turn Treatments
- Restricting Turning Maneuvers
- Pedestrian Signals
- Improve Traffic Control Devices on Minor Intersection Approaches

Experimental

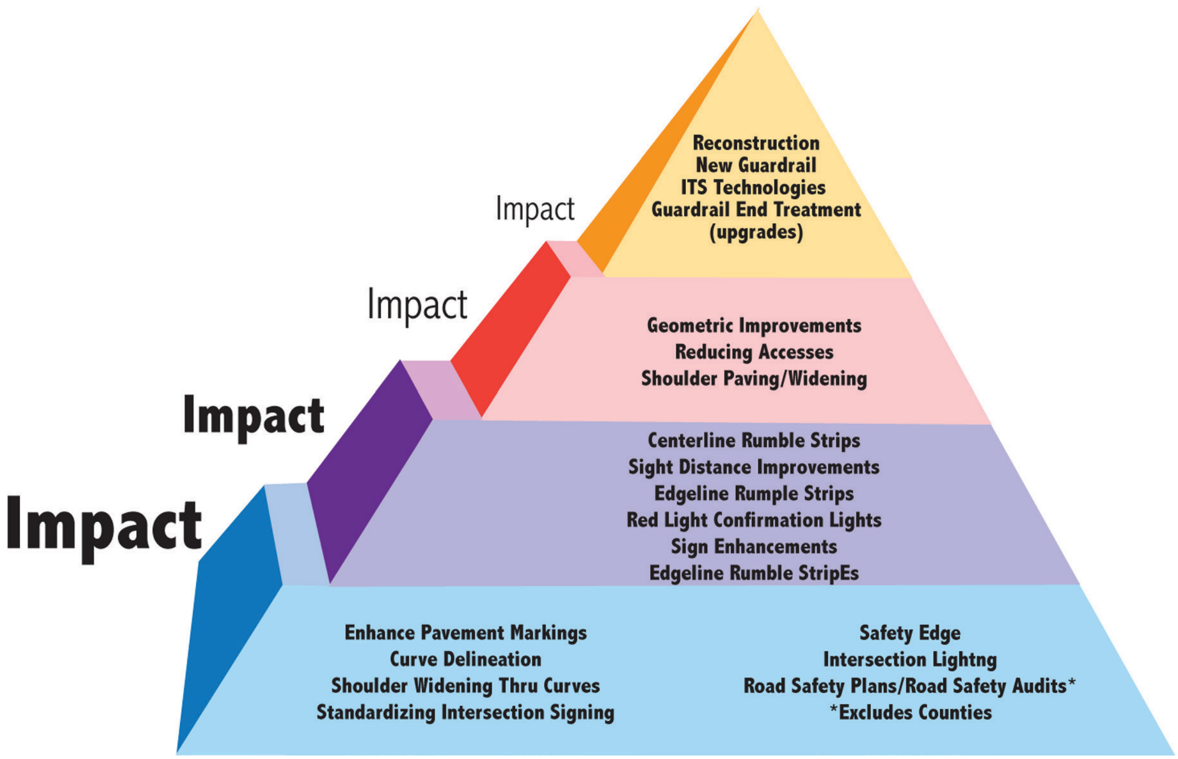
Engineering

- Turn and Bypass Lanes at Rural Intersections
- Dynamic Warning Devices at Horizontal Curves
- Static/Dynamic Gap Assistance Devices
- Delineating Trees in Hazardous Locations
- Marked Pedestrian Crosswalks at Unsignalized Intersections

Highlights

- Traffic engineers have historically had a "tool box" of strategies that could be deployed to address safety concerns. The results of recent safety research studies suggest that the process for originally filling the tool box appears to have been primarily based on anecdotal information.
- The recent research efforts have subjected a number of safety measures to a comprehensive package of comparative and before vs. after analyses and rigorous statistical tests. The results of this research indicate that some safety measures should be kept in the tool box, some removed, some new measures added, and some continued to be studied.
- The 22 volumes that make up the NCHRP Series 500 Reports – Implementation of AASHTO's Strategic Highway Safety Plan – identify over 600 possible safety strategies in categories including driver behavior (speeding, safety belt usage and alcohol), infrastructure related improvements (to reduce head-on, road departure, and intersection crashes) and providing emergency medical services.
- These NCHRP Reports have designated each of the strategies as either Proven (as a result of a rigorous statistical analysis), Tried (widely deployed but no statistical proof of effectiveness), or Experimental (new techniques or strategies and no statistical proof).
- It should be noted that virtually all of the strategies that have been designated in the NCHRP Series 500 Reports as either Proven, Tried, or Experimental are associated with engineering activities. This is due to the lack of published research quantifying the crash reduction effects of strategies dealing with education, enforcement, and emergency services.

Safety Strategies– HSIP Impact Pyramid

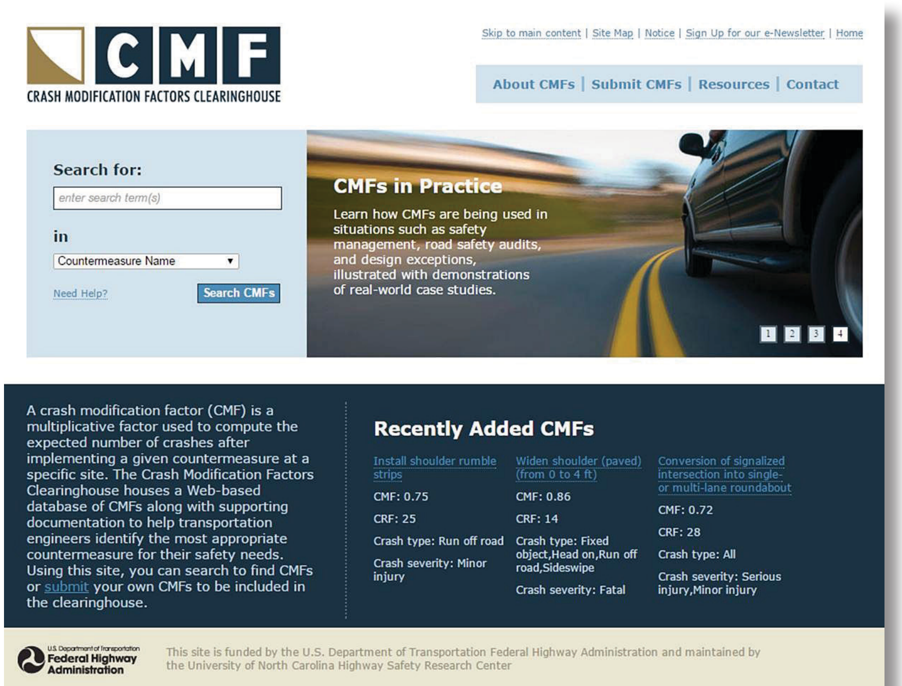


FHWA, Noteworthy Practices: Addressing Safety on Locally Owned and Maintained Roads, A Domestic Scan, August 2010

Highlights

- MnDOT created a visual reference tool, the Highway Safety Improvement Program (HSIP) Impact Pyramid.
- The HSIP Impact Pyramid succinctly shows the relative benefits of various roadway safety measures by grouping individual countermeasures in a hierarchy of four "impact" tiers.
- The pyramid shows the most beneficial strategies on the largest tier (the pyramid base/foundation) and narrows to the least beneficial items on the smallest tier (the pinnacle).
- The HSIP Impact Pyramid reflects MnDOT's preference for systemic HSIP improvements that will result in the greatest impacts to local roadway safety, while acknowledging that reactive site-specific measures must also be considered.
- This tool has helped local agencies understand which improvements are effective, select eligible projects, and reduce crash potential on local roadways.

Safety Strategies – CMF Clearinghouse



Highlights

- The most comprehensive source of information about the effectiveness of the variety of Safety Strategies is FHWA's Crash Modification Factors Clearinghouse (**www.cmfclearinghouse.org**)
- The use of a Crash Modification Factor (CMF) allows the estimation of the long-term changes in the number of crashes that can be expected as a result of implementing a particular strategy at a particular location.
- A CMF is a multiplicative factor – for example a CMF = 0.8 suggests that the implementation of a strategy will reduce crashes to 80% of the historic value. A CMF of 1.1 suggests that implementation will increase crashes to 110% of the historic value.
- The CMF Clearinghouse reports both CMFs and CRFs (Crash Reduction Factors). The CRF represents the expected crash reduction and the CMF is a factor used to estimate the expected number of crashes following implementation of a specific strategy.
- The data presented in the clearinghouse is based on published research and is updated as new reports are added to the database.

Safety Strategies – CMF Clearinghouse

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
0.67	33	★★★★☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.61	39	★★★★☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.71	29	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.75	25	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.75	25	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.7	30	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.58	42	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
1.31	-31	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
1.08	-8	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.57	43	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury	Rural	Torbic et al., 2009	The authors collected data on ... [read more]
0.86	14	★★★☆☆	Run off road	Fatal,Serious injury,Minor injury		Torbic et al., 2009	The authors collected data on ... [read more]

Highlights

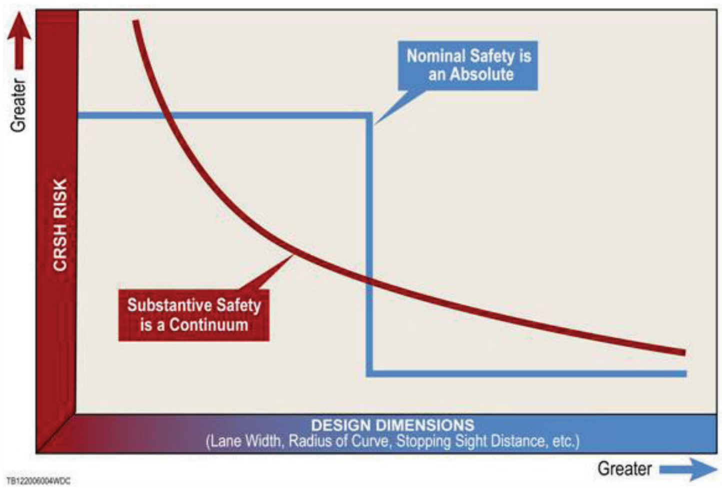
- The results reported in the clearinghouse include:
  - The CMF and CRF
  - A subjective assessment of the results (primarily based on the type of statistical testing reported in the research)
  - Identification of the Crash Type and Severity
  - The Area Type (rural or urban)
  - The Reference (so the entire report can be reviewed)
- The quality assessment involves assigning between zero and 5 stars to each CMFs listed, depending on the type of statistical testing conducted as part of the research. A rating of 5 stars indicates a vigorous program of testing and zero stars indicates no testing. The user can select the quality of the reports, and the higher the rating, the higher the level of confidence in the report value of the CMFs.
- This table of CMFs for Edge Line Rumble Strips shows 11 values, ranging from a 43% reduction in crashes to a 31% increase, with an average of a 20% reduction.

Safety Strategies – Highway Safety Manual

Highlights

- The Highway Safety Manual (HSM) was published by AASHTO in 2010 in order to provide professionals with analytical tools and techniques to quantify the potential effects on crashes as a result of decisions made in planning, design, operations, and maintenance of highway systems.
- A key point is the notion that there is no such thing as absolute safety – there are risks associated with all elements of the system.
- The objective of the HSM is to help practitioners understand and balance safety implications of trade-offs made when assessing the possible social, economic, and environmental effects identified during project development.
- The HSM focuses on how to estimate crash frequency for a particular roadway network, facility or site in the given period – measures of "objective" safety. In contrast, subjective safety concerns the perceptions of how safe drivers feel while on the system. It should be noted that what many drivers feel is based on their intuition as to what is safe. However, research has shown that many elements of traffic safety are counterintuitive.
- Drivers believe that traffic signals are safety devices but the data is conclusive that signalized intersections have more (and more severe) crashes than unsignalized intersections (even when normalized for volume).
- Drivers believe that most drivers Stop at STOP signs but data indicates that fewer than 20% do.
- Drivers believe that most drivers obey the posted speed limit and that lower speeds result in fewer crashes. The data indicates that most drivers will violate a posted limit if it does not approximate the actual 85th percentile speed and crashes are more closely correlated with access density than speed.
- The predictive method in the HSM uses Safety Performance Functions (SPFs) which are regression equations to estimate the average crash frequency for a specific site as a function of traffic volume, cross section and a variety of other characteristics. The HSM encourages users to calibrate the SPFs for their system. This has been done on parts of the Trunk Highway system but not on any local roadways. Without calibration the HSM suggests limiting the analysis to the relative difference between alternatives and not site-specific crash frequencies.

Safety Strategies – Highway Safety Manual

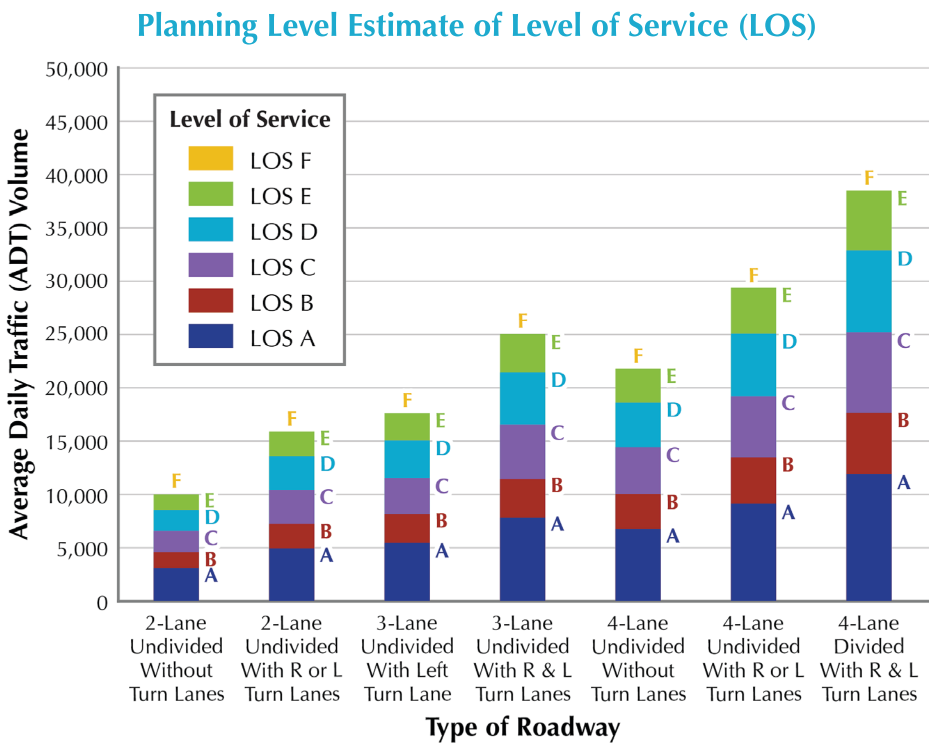


NCHRP Report 480
Transportation Research Board, 2002
FHWA – SA-07-011, Mitigation Strategies for Design Exceptions, 2007

Highlights

- Research is underway to document and quantify the relationship between a roadway's design features and safety characteristics. Current thinking about this relationship suggests there are two dimensions of safety – Nominal and Substantive.
- The concept of nominal safety involves a comparison of the dimensions of design features to an agency's adopted design criteria. In this concept, a roadway or a proposed set of design features is considered to be nominally safe if the features meet or exceed the minimum values. Nominal safety is an absolute, the design features either meet the minimum criteria or they do not.
- The concern with this concept is a recognition that the safety effects of incremental differences in a given design dimension is expected to produce incremental and not absolute change in safety. The nominal safety concept is limited in that it does not address the actual or expected safety performance.
- Substantive safety is defined as the expected long-term safety performance (crash frequency, type, and severity).
- The HSM quantifies these substantive safety relationships where they are known. For example, agencies around the country have worked for years to achieve 12-foot lane widths along rural roadways as a way to optimize safety performance. However, current research indicates that the actual difference in crash frequency is 5% at volumes greater than 2,000 vehicles per day and 1% at volumes under 400 vehicles per day.

Safety Strategies – Highway Capacity Manual



Capacity Assumptions*

Through Only Lane	800 vph
LT/TH Lane	600 vph
TH/RT Lane	700 vph
TH/RT/FT Lanes	600 vph
Turn Lanes	350 vph

* Assumes 1/4 mile signal spacing. For less than 1/4 mile signal spacing, roadway becomes too volatile to determine LOS by ADT.

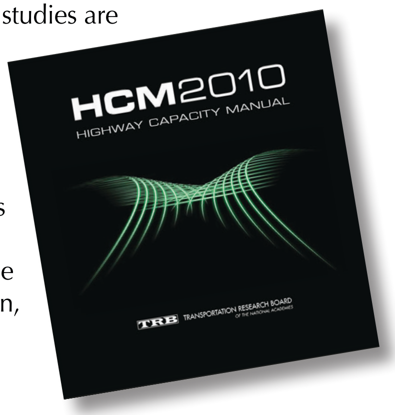
Peak Hour Percentages

Arterial Roadway	10%
Directional Orientation	60/40

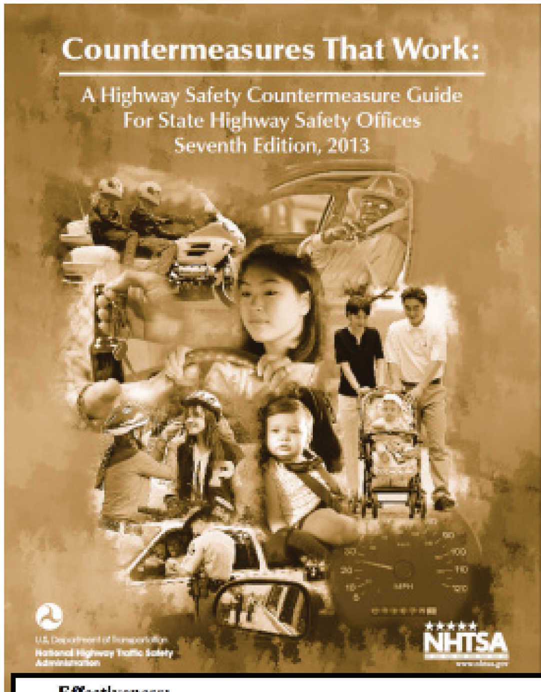
Note: Approximate values based on highly dependent assumptions. Do not use for operational analyses or final design.

Highlights

- Recent research has identified a relationship between traffic safety and traffic operations, with certain types of roadways experiencing higher numbers of crashes as levels of congestion increases.
- The Highway Capacity Manual (HCM) provides analytical techniques to assist engineers and planners document the quality of the traffic operation (the level of congestion) based on set of variables, including; traffic characteristics, roadway characteristics and intersection controls.
- The current edition (2010) is the first HCM to provide a multimodal approach to the analysis and evaluation of urban streets from the point of view of drivers, transit, bicyclists and pedestrians. This edition also provides tools and generalized service volumes to assist in sizing future facilities.
- The Federal Highway Administration has developed a new tool – The Capacity Analysis for Planning of Junctions (CAP-X) – that can be used to evaluate a variety of types of innovative junction designs (eight intersections, five interchanges, three roundabouts and two mini-roundabouts).
  - **http://www.fhwa.dot.gov/software/research/operations/cap-x/**
- Traffic operations analyses to support design level studies are based on peak traffic flows. However, an under-standing of the relationship between traffic volume and roadway cross-section can add value to system planning efforts. To aid these planning studies, efforts have been made to develop estimates of the level of congestion across generalized roadway types based on daily traffic volumes and assumed values for details such as the fraction of peak hour traffic, directional distribution, pedestrians and heavy vehicles.



Safety Strategies– Countermeasures that Work



Effectiveness:

★★★★★ - Demonstrated to be effective by several high-quality evaluations with consistent results

★★★★ - Demonstrated to be effective in certain situations

★★★ - Likely to be effective based on balance of evidence from high-quality evaluations or other sources

★★ - Effectiveness still undetermined; different methods of implementing this countermeasure produce different results

★ - Limited or no high-quality evaluation evidence

Effectiveness is measured by reductions in crashes or injuries unless noted otherwise. See individual countermeasure descriptions for information on effectiveness size and how effectiveness is measured.

Highlights

- This guide is a basic reference to assist State Highway Safety Offices in selecting effective, evidence-based countermeasures for behavioral traffic safety problems areas including:
  - Alcohol-impaired and Drugged Driving
  - Seat Belts and Child Restraints
  - Aggressive Driving and Speeding
  - Distracted and Drowsy Driving
  - Motorcycle Safety
  - Young Drivers
  - Older Drivers
  - Pedestrians
  - Bicycles
- The guide contains information on each problem area including a brief overview of the problem area's size and characteristics, the main countermeasure strategies, along with a table that lists specific countermeasures and summarizes their effectiveness, costs, use, and implementation time.

Safety Strategies – Infrastructure

Strategy	Crash Reduction Factor[a]
Urban	
Conversions (3-lane/5-lane)	30% to 50%
Access Management	5% to 31%
Signal - Confirmation Lights	25% to 84% reduction in violations
Pedestrian/Bike - Advanced Walk	Up to 60% ped/vehicle crashes
Pedestrian/Bike - Countdown Timers	25% ped/vehicle crashes
Pedestrian/Bike - Curb Extensions	Increase in vehicles yielding to pedestrians
Pedestrian/Bike - Median Refuge Island	46% in vehicle/pedestrian crashes
Rural Segments	
6-inch Latex Edge Line	10% to 45% all rural serious crashes
Rumble Strip/stripE	20% run off road crashes
2-ft Paved Shoulder + Rumble Strip	20% to 30% run off road crashes
Centerline Rumble Strip	40% head on/sideswipe crashes
4-ft Buffer	Under Evaluation[b]
12-ft Buffer with Left Turn Lanes	50% all crashes / 100% head-on crashes[c]
Rural Curves	
Chevrons	20% to 30%
Edgeline Rumble Strip	20% run off road crashes
2-ft Paved Shoulder + Rumble Strip	20% to 30% run off road crashes
Rural Intersections	
Roundabout	20% - 50% All Crashes / 60% - 90% right angle
RCI, or J-Turn	17% all crashes / 100% angle crashes
Mainline Dynamic Warning Sign	50% all crashes / 75% severe right angle crashes
Intersection Lighting	25% to 40% nighttime crashes
Upgrade Signs and Markings	40% upgrade of all signs and marking / 15% for STOP AHEAD marking
Clear Sight Triangle	37% serious injury crashes[d]

[a] Crash reduction factors based on review of CMF Clearinghouse and other published research
[b] MnDOT experience on TH 12 in Long Lake
[c] MnDOT experience on TH 5 in Lake Elmo
[d] Reduction based on increasing sight distance triangle

Highlights

- The safety plan prepared for every county in Minnesota focused on maximizing the use of proven effective strategies. The use of these strategies provides both the safety project developers and MnDOT safety program managers the highest level of confidence that the proposed implementation will result in similar outcomes achieved by the deployment reported in the published literature – a particular crash reduction.
- The table at left documents the 22 basic safety strategies that were used in the development of the County Roadway Safety Plan. Twelve of the strategies were considered Proven effective, with CRFs generally in the 20% to 30% range. Nine of the strategies were considered Tried, with CRFs again generally around 30%. One strategy (the RCUT or channelized median intersection) was considered Experimental – but in limited deployment in Minnesota and around the County, this strategy has in each case resulted in a virtual elimination of right angle crashes.

Safety Strategies – Behavior

Alcohol

2. Deterrence: Enforcement

Countermeasure	Effectiveness	Cost	Use	Time
2.1 High visibility sobriety checkpoints	★★★★★	$$$	Medium	Short
2.2 High visibility saturation patrols	★★★★	$$	High	Short
2.3 Preliminary Breath Test devices (PBTs)†	★★★★	$$	High	Short
2.4 Passive alcohol sensors††	★★★★	$$	Unknown	Short
2.5 Integrated enforcement	★★★	$	Unknown	Short

† Proven for increasing arrests
†† Proven for detecting impaired drivers

Unbelted

2. Seat Belt Law Enforcement

Countermeasure	Effectiveness	Cost	Use	Time
2.1 Short high-visibility belt law enforcement	★★★★★	$$$	Medium†	Medium
2.2 Combined enforcement, nighttime	★★★★	$$$	Unknown	Medium
2.3 Sustained enforcement	★★★	Varies	Unknown	Varies

† Used in many jurisdictions but often only once or twice each year

Inattentive

1. Laws and Enforcement

Countermeasure	Effectiveness	Cost	Use	Time
1.1 GDL requirements for beginning drivers	★★★★★†	$	High	Medium
1.2 Cell phone and text messaging laws	★★	$	Medium	Short
1.3 High Visibility Cell phone/text messaging enforcement	★★★★	$$$	Low	Medium
1.4 General drowsiness and distraction laws	★	Varies	High††	Short

† Effectiveness proven for nighttime and passenger restrictions

Speed

2. Enforcement

Countermeasure	Effectiveness	Cost	Use	Time
2.1 Automated enforcement	★★★★★	$$$†	Medium	Medium
2.2 High-visibility enforcement	★★	$$$	Low††	Medium
2.3 Other enforcement methods	★★	Varies	Unknown	Varies

† Can be covered by income from citations
†† For aggressive driving, but use of short-term, high-visibility enforcement campaigns for speeding is more widespread

Highlights

- The tables at left summarize the behavior strategies from *Countermeasures that Work* for behavioral focus areas.
- **Cost to implement:**
  - **$$$:** requires extensive new facilities, staff, equipment, or publicity, or makes heavy demands on current resources
  - **$$:** requires some additional staff time, equipment, facilities, and/or publicity
  - **$:** can be implemented with current staff, perhaps with training; limited costs for equipment, facilities, and publicity
  - These estimates do not include the costs of enacting legislation or establishing policies.
- **Use:**
  - **High:** more than two-thirds of the States, or a substantial majority of communities
  - **Medium:** between one-third and two-thirds of States or communities
  - **Low:** less than one-third of the States or communities
  - **Unknown:** data not available
- **Time to implement:**
  - **Long:** more than one year
  - **Medium:** more than three months but less than one year
  - **Short:** three months or less
  - These estimates do not include the time required to enact legislation or establish policies.

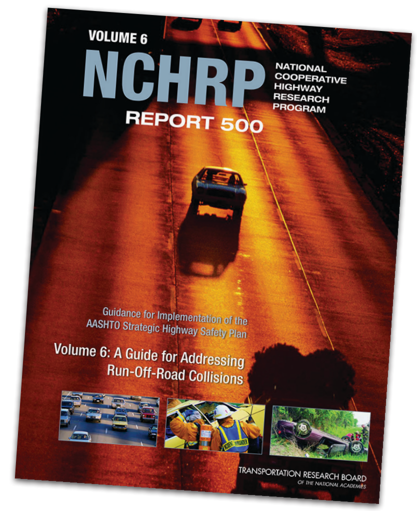
Roadside Safety Initiatives

Emphasis Area Objectives and Strategies	
Objectives	**Strategies**
15.1 A – Keep vehicles from encroaching on the roadside	15.1 A1 – Install shoulder rumble strips 15.1 A2 – Install edgeline “profile marking,” edgeline rumble strips, or modified shoulder rumble strips on section with narrow or no paved shoulders 15.1 A3 – Install midlane rumble strips 15.1 A4 – Provide enhanced shoulder or in-lane delineation and marking for sharp curves 15.1 A5 – Provide improved highway geometry for horizontal curves 15.1 A6 – Provide enhanced pavement markings 15.1 A7 – Provide skid-resistant pavement surfaces 15.1 A8 – Apply shoulder treatments Eliminate shoulder drop-offs Widen and/or pave shoulders
15.1 B – Minimize the likelihood of crashing into an object or overturning if the vehicle travels off the shoulder	15.1 B1 – Design safer slopes and ditches to prevent rollovers 15.1 B2 – Remove/relocate objects in hazardous locations 15.1 B3 – Delineate trees or utility poles with retroreflective tape
15.1.C – Reduce the severity of the crash	15.1 C1 – Improve design of roadside hardware (e.g., light poles, signs, bridge rails) 15.1 C2 – Improve design and application of barrier and attenuation systems

NCHRP Report 500 Series (Volume 6)

Highlights

- Single vehicle road departure crashes have been identified as being one of Minnesota’s safety focus areas.
- Single vehicle road departure crashes account for 32% of all fatal crashes in Minnesota and as much as 47% of fatal crashes on local roads in rural areas.
- The guidance in the NCHRP Service 500 Report – Volume 6 suggests a three-step process for addressing road departure crashes:
  1. Keep vehicles on the road
  2. Provide clear recovery areas
  3. Install/upgrade highway hardware



- This three-step priority is based on cost considerations, feasibility, and logic. The strategies associated with keeping vehicles on the road are generally low cost, can easily be implemented because additional right-of-way and detailed environmental analyses are not required, and treating road edges directly addresses the root cause of the problem – vehicles straying from the lane.
- Providing clear recovery areas is considered to be the second priority even though the strategies have been proven effective, because of implantation challenges – costs are generally higher than for edge treatments, and additional right-of-way may be required as well as a more detailed environmental review.
- Installing/upgrading highway hardware is the third priority because it can be expensive to construct and maintain, it can cause injuries when hit, and it does not address the root cause of the problem.

Roadside Safety Initiatives – Edge Treatments

Highlights

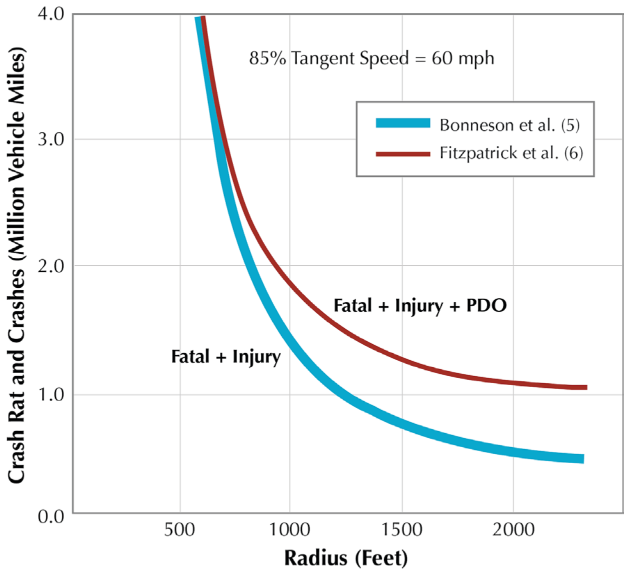
- Typical edge treatments include shoulder/edgeline rumble strips, enhanced pavement markings, and eliminating shoulder drop-offs.
- Implementation costs vary from low cost (safety edge) to several thousand dollars per mile for rumble strips/stripEs and embedded wet reflective markings.
- National safety studies have documented crash reductions in the range of 20% to 50% for road departure crashes.
- Additional benefits have been observed on projects where edgelines have been painted over the edgeline rumble strips – nighttime visibility in wet pavement conditions was improved (the reflective beads applied to the nearly vertical face of the rumble strip remain above the film of water on the pavement surface) and the life of the pavement marking was extended (snow plows cannot scrape away the beads on the vertical faces).
- St. Louis County has installed 114 miles of rumble strips and 82 miles of rumble stripEs and has documented a substantial reduction in pavement marking maintenance costs.

Roadside Safety Initiatives – Edge Treatments

Highlights

- The installation of edge rumble strips has proven to be effective at reducing lane departure crashes, the most frequent type in Greater Minnesota.
- They have generated complaints about noise, bicycle safety, and accommodating farm equipment.
- MnDOT has conducted noise studies that indicate rumbles will increase noise levels, but not beyond established thresholds.
- To reduce the chance of bicycles having to traverse a rumble strip, MnDOT has adopted the use of an innovative design that provides 12 feet of smooth pavement edge between 48 foot sections with grooves. This design provides bicyclists with the opportunity to move from the travel lane to the refuge of the shoulder when being overtaken by a vehicle without having to traverse the rumbles.
- Another strategy for reducing the number of complaints about noise is to consider both the volume of traffic and the density of adjacent residential development as part of a systemic risk assessment. Focusing the installation of edge rumbles on roadways with few widely spaced homes has been used successfully by a number of counties in Minnesota.
- If a roadway with a high density of residential development is identified as a priority for lane departure crashes, consideration should be given to substituting an embedded wet reflective edgeline for the edge rumble. The embedded wet reflective edge line will provide enhanced nighttime wet pavement edge delineation without concerns for traffic noise. The only disadvantage of the embedded wet reflective strategy are somewhat high cost and the effect on lane departure crashes is not yet known.
- Another alternative to address noise concerns associated with ground-in rumble strips is currently being investigated and involves the use of a sinusoidal profile. Initial tests of the "quiet" rumble indicate they produce noise levels in the range of 3 to 6 decibels below the ground-in rumble strips.

Roadside Safety Initiatives–Horizontal Curves



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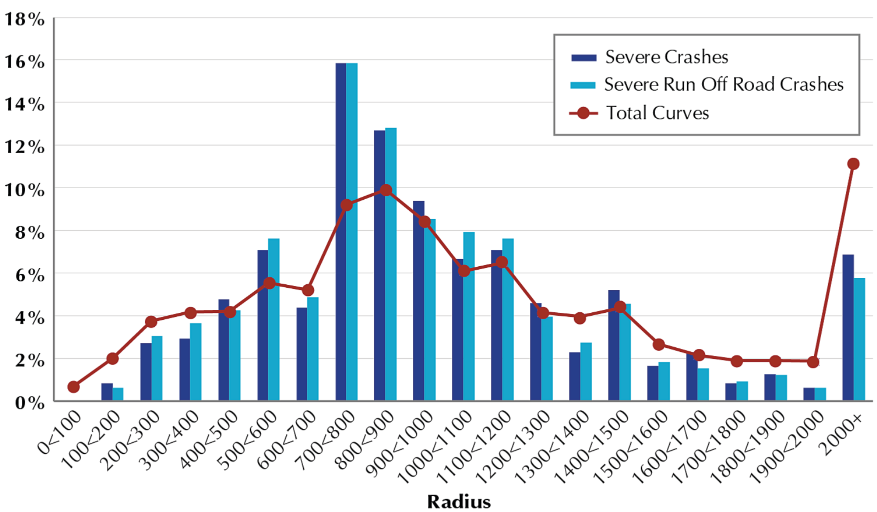


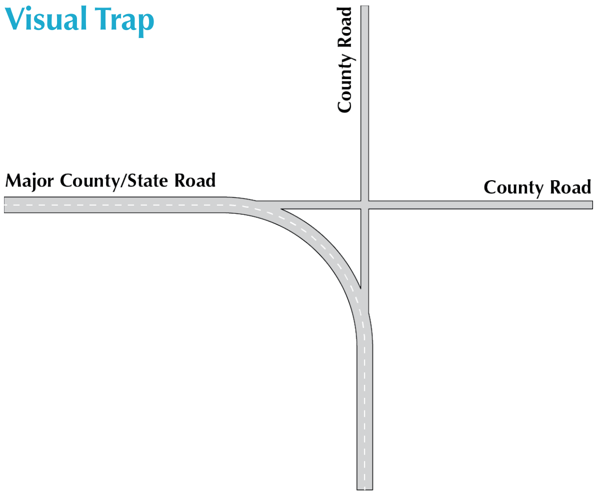
Minnesota County Road Safety Plans, Data 2007-2011

Highlights

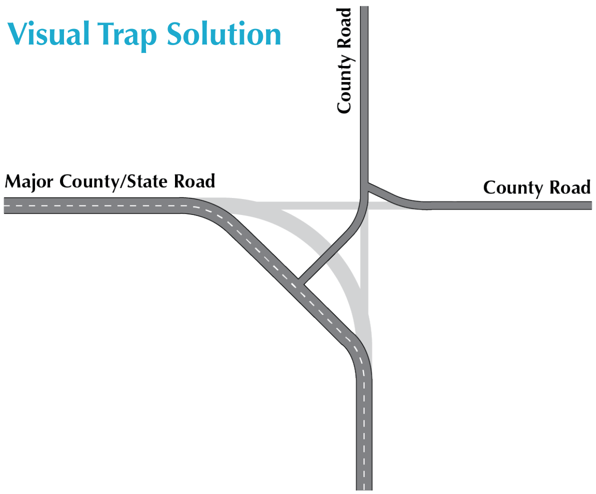
- A number of previously published research reports have identified horizontal curves as at-risk elements or rural roads systems, however, the degree of risk was not quantified.
- A recent report prepared by the Texas Transportation Institute (TTI) (FHWA/X-07/0-5439-1) related actual crash rates on rural roads to the radius of curvature. The results of this research indicate that the crash rate on curves with radii greater than 2,500 feet is approximately equal to the crash rate on tangent sections.
- On curves with radii of 1,000 feet, the crash rate is twice the rate on tangents and curves; curves with radii of 500 feet are equal to the crash rate on tangent sections.
- The analysis of approximately 19,000 horizontal curves along rural county highways in Minnesota found results similar to the TTI research. Curves with radii between 500 feet and 1,200 feet were most at-risk.
- Curves with radii within this 500- to 1,200-foot range accounted for approximately 50% of curves but 70% of severe road departure crashes. These curves also had the highest density of severe crashes.
- Other key findings include:
  - Even though 50% of all severe road departure crashes along rural county highways occur in a horizontal curve, 95% of the curves had NO severe crashes during a 5-year study period.
  - 2% of curves had ONE severe crash.
  - There are NO “Dead Man’s Curve” – no curve averaged one severe crash per year.
  - The average crash density was 0.005 severe crashes/curve/year.
- The analysis of horizontal curves along rural county highways in Minnesota identified more than 10,000 curves as high priority candidates for safety improvement based on the presence of particular roadway and traffic characteristics. The suggested safety improvement at each of these high priority curves involved the installation of chevrons and edge line rumble strips that had an average cost of slightly more than $7,000 per curve.

Roadside Safety Initiatives– Horizontal Curves

Visual Trap



Visual Trap Solution



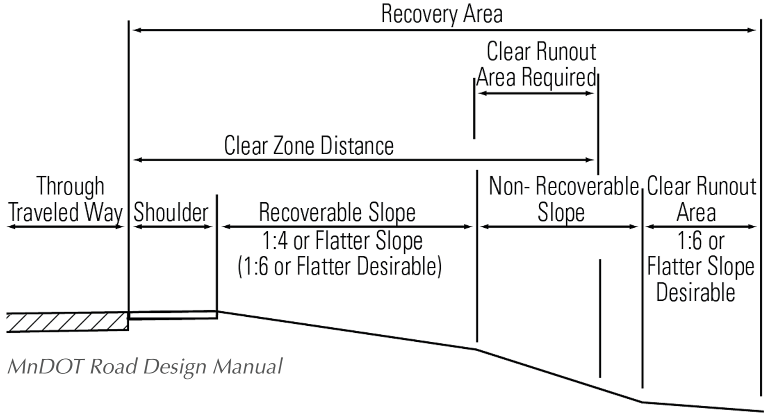
Highlights

- In rural Minnesota the local road system is a grid of north/south and east/west section line roads. This grid system results in numerous locations where local roads intersect with paved county roads and state highways in horizontal curves.
- The analysis of horizontal curves that was conducted as part of the County Road Safety Plans found that curves that contained an intersection had a higher crash frequency than comparable curves without an intersection.
- The presence of an intersection in a curve also produces a condition called a "visual trap" causing a driver on the major road to see a roadway continue on the tangent when the major road actually turns. The analysis found that curves with "visual traps" have a higher frequency of crashes than comparable curves without.
- The analysis of rural intersections found that intersections in curves had a higher frequency of crashes than comparable intersections located on tangent sections. It appears that closely spaced intersection with skewed approaches to the major road increase the risk for intersection crashes (see figure to the left). The preferred solution for improving the multiple intersection curve involved reconstructing to provide a single "T" intersection where the minor leg is perpendicular to the major road.
- Beyond the use of typical low cost improvements, such as chevrons and edgeline rumble strips, additional design strategies could be providing strategically placed vegetation to address the "visual trap" issue and possibly replacing the single horizontal curve with two curves separated by a tangent section.
- The preferred solution, reconstructing the roadways, is not a low-cost solution and would likely not be a candidate for safety funding.

Example of a Visual Trap

Roadside Safety Initiatives – Slope Design/Clear Recovery Areas

Slope Design



MnDOT Road Design Manual

Example #1

- 6:1 Slope (Fill Slope)
- 60 MPH
- 5,000 ADT

Answer: CZ = 30 Feet

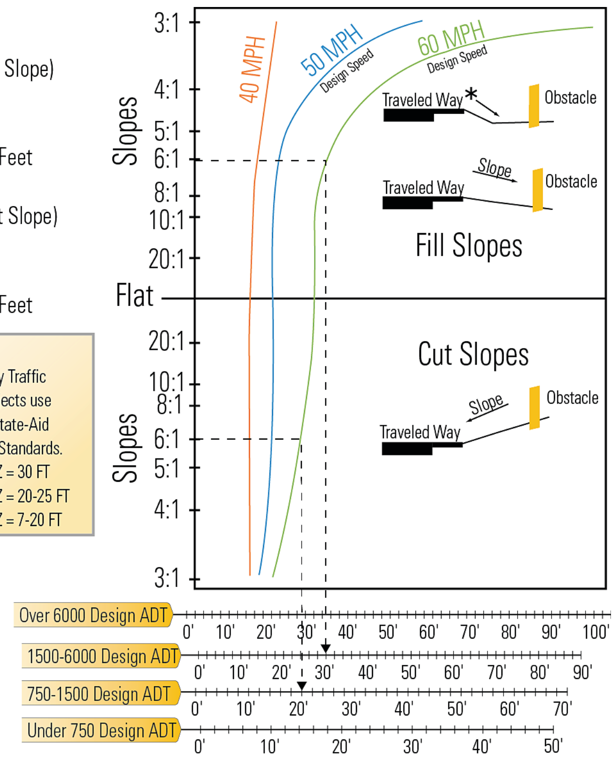
Example #2

- 6:1 Slope (Cut Slope)
- 60 MPH
- 750 ADT

Answer: CZ = 20 Feet

CZ = Clear Zone
ADT = Average Daily Traffic
Note: State-Aid projects use the Mn/Dot State-Aid Rural Design Standards.

Over 1,500 ADT;	CZ = 30 FT
750-1,500 ADT;	CZ = 20-25 FT
0-750 ADT;	CZ = 7-20 FT



Clear Zone Distance(CZ)

* See Mn/DOT Road Design Manual section 3.3.4 for a discussion on variable slope determination

Highlights

- Efforts to improve clear zones are usually part of reconstruction projects because of higher costs associated with flattening slopes and reconstructing ditches. Other roadside elements typically addressed as an integral part of reconstruction include: tree removal, flattening slopes at driveways and field entrances, removing unnecessary entrances, relocating utility poles (if the right-of-way is wide enough) and upgrading roadside hardware.
- The recommended clear zone distance is a function of speed, slope, volume, and horizontal curvature.
- Generally, higher speeds, steeper fill slopes, higher volumes, and locations along the outsides of horizontal curves require larger clear zones.
- The concept of providing clear recovery areas is primarily intended for rural roadways. However, the concept can be applied to suburban or urban roadways if road departure crashes are a concern.

Roadside Safety Initiatives–Upgrade Roadside Hardware

Compliant

Example implementations compliant (above) and not compliant (below) with current standards (NCHRP 350)

Noncompliant

Highlights

- Upgrading roadside hardware is typically a part of ongoing highway maintenance and reconstruction programs. Projects to upgrade traffic signs should address sign posts. All sign posts located in the clear zone on roads with speed limits greater than 50 miles per hour are required to have a breakaway design or be protected by a barrier or crash cushion. Guardrails are typically installed or upgraded as part of highway reconstruction projects. It should be noted that the use of guardrails are typically reserved for higher volume roadways (over 400 vehicles per day) due to the high cost of installation plus ongoing maintenance.
- All highway hardware must meet the requirements in 2009 the AASHTO Manual for Assessing Safety Hardware (MASH).
- Typical treatments and their installation costs include the following:
  - Impact attenuator = $20,000
  - Guardrail terminal = $1,500
  - Guardrail transition = $1,000
  - Cable or W-Beam Guardrail = $75,000 - $150,000 per mile
- It is considered a best practice to upgrade roadside hardware as a part of reconstruction projects because of safety benefits associated with reducing the severity of collisions with structures that agencies install along road edges, including sign posts, mailbox supports, and guardrails. However, it should be noted that efforts focused on only upgrading hardware (as opposed to also improving road edges and clear zones), while nominally addressing safety would be expected to provide a limited increase in substantive safety because of the relatively few reported crashes with these types of structures.

Effectiveness of Roadside Safety Initiatives

TH 6 NOW	TH 6 THEN		TH 38 THEN	TH 38 NOW
11.2	11.2	Length (Miles)	11.2	11.2
9	23	Total Crashes (5 Years)	51	10
3	11	PDO Crashes	25	5
5	12	Injury Crashes	26	5
1	0	Fatal Crashes	0	0
575	1,100	Volume (VPD)	1,100	1,200
11.75	22.48	MVM	22.48	24.53
0.8	1.0	Crash Rates (Crashes/MVM)	2.3	0.4
1.5	1.5	Severity Rate	4.1	0.7
1.0	1.3	Critical Crash Rates	1.3	0.9
3 (33%)	10 (43%)	SVRD Crashes	37 (73%)	8 (80%)
2	3	Hit Trees	30	3
0	8 (35%)	Passing Crashes	3 (6%)	0
4	2	Angle Crashes	4	1
2	6	Deer Hits	1	1
0	10 (43%)	Night	21 (41%)	4 (40%)

PDO Property Damage Only
VPD Vehicles Per Day
MVM Million Vehicle Miles
SVRD Single Vehicle Road Departure

Minnesota Crash Mapping Analysis Tool

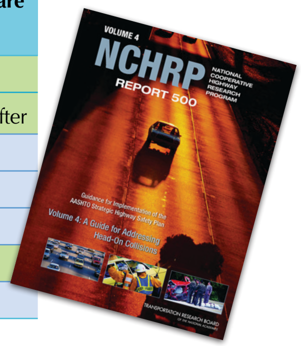
Highlights

- An estimate of the safety implications by evaluating two very similar segments of two-lane rural trunk highways in northern Minnesota: TH 6 and TH 38.
- Both roads have the following similar characteristics:
  - Have low volumes
  - Serve similar functions (recreational and logging)
  - Traverse the Chippewa National Forest
  - Have scenic qualities
- In 2008, TH 6 had been reconstructed and TH 38 had not. (Note: This segment of TH 38 has recently been reconstructed but a Before vs. After Study has not been completed.)
- The differences in crash characteristics TH 38 had are substantial:
  - More than twice as many crashes
  - More than twice as many injuries
  - A crash rate more than twice the average for two-lane rural roads (and 30% greater than the critical rate)
  - Almost four times as many SVRD crashes (and more than three the average for similar roads).
  - Ten times as many tree hits
  - More than twice as many nighttime crashes
- TH 38 has since been reconstructed and the crash reduction has been substantial – almost 80% reduction in the number and rate of crashes. TH 38 now has safety characteristics below the norms for similar roadways.
- During the same time period, TH 6 also experienced a crash reduction consistent with statewide trends and continues to operate within the typical range for two-lane rural roadways.

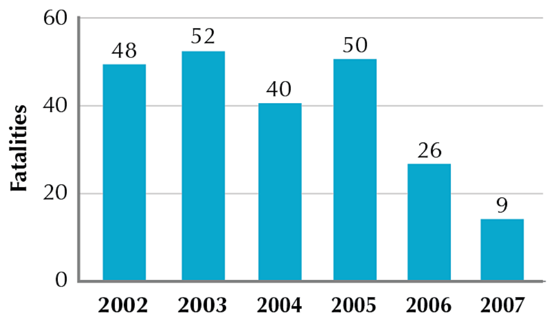
Addressing Head-On Collisions

Head–On Crashes on a Two–Lane Rural Highway in Delaware Before and After Use of Centerline Rumble Stripe		
	Head–On Crash Frequency	
Severity of Crash	36 Months Before	24 Months After
Fatal	6	0
Injury	14	12
Damage Only	19	6
Total	39	18
Crashes per Month	1.1	0.76

NCHRP 500 Series (Volume 4)

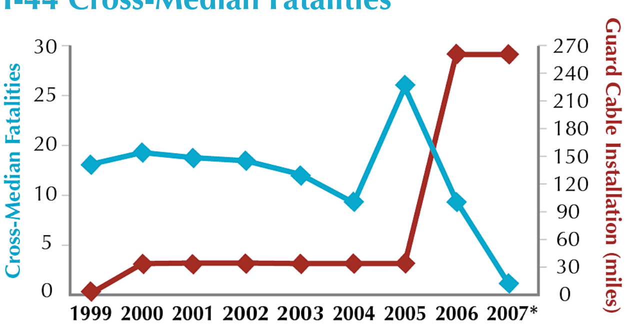


Interstate Cross-Median Fatalities



Fatal Head-On Crashes on Rural Two-Lane Two-Way Highways in Minnesota, Derek Leuer, MnDOT, January 2015

I-44 Cross-Median Fatalities

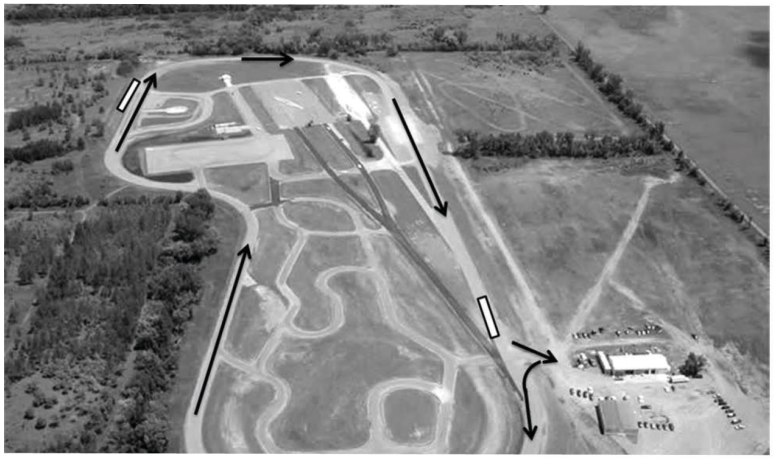


AASHTO, "Driving Down Lane Departure Crashes", April 2008

Highlights

- Head-on crashes account for approximately 20% of the traffic fatalities in Minnesota.
- Addressing head-on crashes is one of Minnesota's critical safety focus areas.
- Minnesota averages approximately 120 fatal head-on crashes per year, 97% are NOT passing related on two-lane facilities, 63% are on the state system, and about 75% are in rural areas.
- Centerline rumble strips have been found to reduce head-on crashes along two-lane roads – data from 98 sites in seven states (including Minnesota) indicated significant reductions for injury crashes (15%) as well as for head-on and opposing sideswipe injury crashes (25%).
- Additional strategies for two-lane roads include conducting field surveys to confirm that designated passing zones meet current guidelines for sight distance and the use of thermoplastic markings where passing is not permitted.
- The construction of "Passing Lanes" along two-lane roads has been found to be a convenience for motorists (providing opportunities to pass slower moving vehicles). However, there is no evidence that the passing lanes have reduced head-on crashes.
- A number of states have begun to address cross-median head-on crashes on divided highways by installing cable median barriers. Reported reductions in severe head-on crashes have ranged from 70% to 95%.
- MnDOT has installed approximately 450 miles of cable barrier, with plans to install an additional 80 miles. A preliminary analysis of MnDOT's first cable median barrier installation (along I-94 in Maple Grove) found a 100% reduction in fatalities and a 90% reduction in overall crash severity.

Addressing Head-On Collisions



Investigators observed motorcyclists circuit a 1-mile course with rumble strips,

Highlights

- A recent local study on effects of centerline rumble strips on over 200 miles of rural roadways in Minnesota found 40% to 76% reduction in encroachments and a 73% lower fatal and severe crash rates and 42% lower crash rate overall than locations without centerline rumbles.
- An additional study to determine if centerline rumble strips contribute to motorcycle crashes or negatively affect motorcycle rider behavior was conducted by MnDOT in 2008. The study analyzed crash data and observations from a closed-circuit course with 32 riders of various motorcycle types.
- The closed-circuit course observations showed no steering, braking, or throttle adjustment during strip crossings by the riders. In post-circuit interviews, no rider described the strips as a hazard.
- Out of over 9,000 motorcycle crashes reviewed, only 29 occurred at locations with rumbles present. None of the crash reports mention rumble strips as a factor.

Safety Effects of Centerline Rumble Strips in Minnesota (**www.lrrb.org/media/reports/200844ts.pdf**)

Effects of Centerline Rumble on Motorcycles: NCHRP 641 226 (**www.lrrb.org/media/reports/200807TS.pdf**)

Intersection Safety Strategies

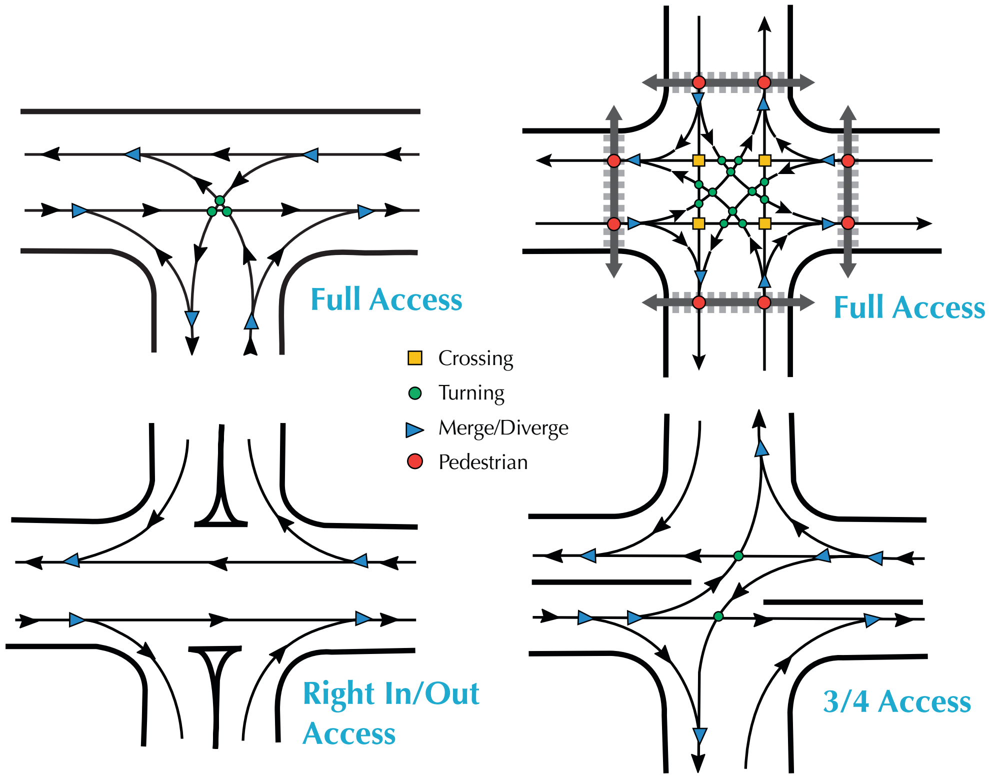
Objectives	Strategies	Relative Cost to Implement and Operate	Effectiveness	Typical Timeframe for Implementation
A - Improve access management	A1- Implement intersection or driveway closures, relocations, and turning restrictions using signing or by providing channelization.	Low to Moderate	Tried	Medium (1-2 yrs)
B - Reduce the frequency and severity of intersection conflicts through geometric design improvements	B1- Provide left-turn lanes at intersections; provide sufficient length to accommodate deceleration and queuing; and use offset turn lanes to provide better visibility if needed.	Moderate to High	Proven	Medium (1-2 yrs)
	B2 - Provide bypass lanes on shoulders at T-intersections.	Low	Tried	Short (<1 yr)
	B3 - Provide right-turn lanes at intersections; provide sufficient length to accommodate deceleration and queuing; use offset turn lanes to provide better visibility if needed; and provide right-turn acceleration lanes.	Moderate to High	Proven	Medium (1-2 yrs)
	B4 - Realign intersection approaches to reduce or eliminate intersection skew.	High	Proven	Medium (1-2 yrs)
C - Improve driver awareness of intersections as viewed from the intersection approach.	C1 - Improve visibility of intersections by providing enhanced signing. This may include installing larger regulatory, warning, and guide signing and supplementary stop signs.	Low	Tried	Short (<1 yr)
	C2 - Improve visibility of intersections by providing lighting (install or enhance) or red flashing beacons mounted on stop signs.	Low to Moderate	Proven	Medium (1-2 yrs)
	C3 - Improve visibility of intersections by providing enhanced pavement markings, such as adding or widening stop bar on minor-road approaches, supplementary messages (i.e., STOP AHEAD).	Low	Tried	Short (<1 yr)
	C4 - Improve visibility of traffic signals using overhead mast arms and larger lenses.	Moderate	Tried	Short (<1 yr)
	C5 - Deploy mainline dynamic flashing beacons to warn drivers of entering traffic.	Low	Experimental	Short (<1 yr)
D - Improve sight distance at intersections.	D1 - Clear sight triangles approaches to intersections; in addition to eliminating objects in the roadside, this may also include eliminating parking that restricts sight distance.	Low to Moderate	Tried	Short (<1 yr)
E - Choose appropriate intersection traffic control to minimize crash frequency and severity	E1 - Provide all-way stop control at appropriate intersections.	Low	Proven	Short (<1 yr)
	E2 - Provide roundabouts at appropriate intersections.	High	Proven	Long (>2 yrs)
F - Improve driver compliance with traffic control devices and traffic laws at intersections	F1 - Enhance enforcement of red-light running violations using automated enforcement (cameras) or adding confirmation lights on the back of signals to assist traditional enforcement methods.	Moderate	Proven/Tried	Medium (1-2 yrs)
G - Reduce frequency and severity of intersection conflicts through traffic signal control and operational improvements.	G1 - Employ multiphase signal operation, signal coordination, emergency vehicle preemption optimize clearance intervals; implement dilemma zone protection; on high speed roadways, install advance warning flashers to inform driver of need to stop; and retime adjacent signals to create gaps at stop-controlled intersections.	Low to Moderate	Proven/Tried	Medium (1-2 yrs)

MnDOT Strategic Highway Safety Plan, 2014

Highlights

- Addressing crashes at intersections is one of Minnesota's safety focus areas.
- Intersection-related crashes account for more than 50% of all crashes and about one-third of fatal crashes.
- Approximately two-thirds of fatal intersection crashes occur in Greater Minnesota and slightly more than one-half are on the local system.
- STOP-controlled intersections average slightly less than one crash per year and signalized intersections average almost seven crashes per year.
- The high-priority safety strategies for unsignalized intersections involve managing access and conflicts, enhancing signs and markings, improving intersection sight distance, and providing roundabouts.
- The high-priority strategies for signalized intersections include reducing red light violations and optimizing signal operations.
- On the state system, about 55% of intersection crashes occur at locations with STOP control. However, there are seven times as many STOP-controlled as compared to signal-controlled intersections.
- The density of severe crashes (Fatals & A Injuries) is four times higher at signalized intersections than at STOP-controlled intersections.
- MnDOT has developed a tool to assist highway agencies with choices about intersection control. The Intersection Control Evaluation (ICE) guidelines provides directions and recommendations for an objective analysis of safety and traffic operations performance measures for a variety of alternative control strategies with the goal of helping agencies determine the optimal intersection control for a given set of roadway and traffic conditions.

Intersections – Conflict Points
Traditional Design



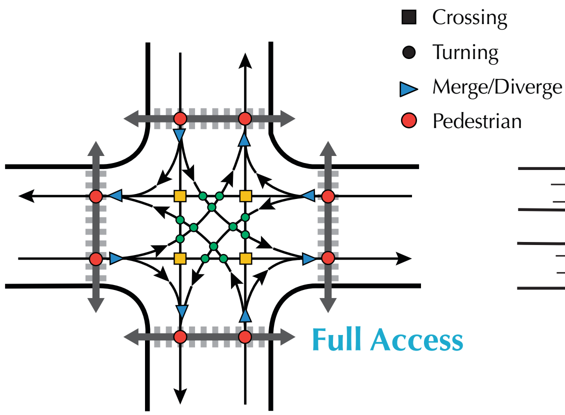
	Crossing	Turning	Merge/ Diverge	Total	Typical Crash Rate (crashes per mil. entering vehicles)
Full Access +	4	12	16	32	0.7
Full Access T	0	3	6	9	0.4
3/4 Access	0	2	8	10	0.5
Right In/Out Access	0	0	4	4	0.2

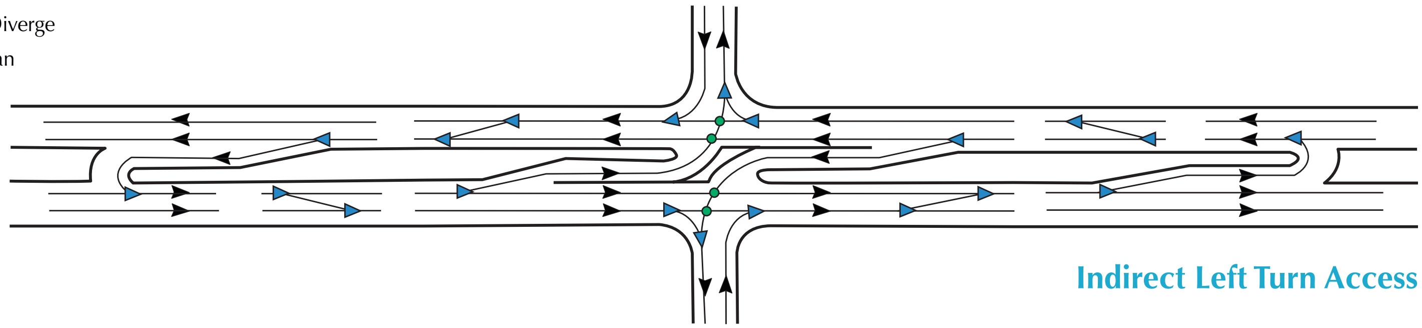
2013 MnDOT Crash Data Toolkit

Highlights

- A review of the safety research suggests that intersection crash rates are related to the number of conflicts at the intersection.
- Conflict points are locations in or on the approaches to an intersection where vehicle paths merge, diverge, or cross.
- The actual number of conflicts at an intersection is a function of the number of approaching legs ("T" intersection have fewer conflicts than four-legged intersections) and the allowed vehicle movements (intersections where left turns are prohibited/prevented have fewer conflicts than intersections where all movements are allowed).
- A preliminary review of intersection crash data indicates two key points:
  - Some vehicle movements are more hazardous than others. The data indicates that minor street crossing movements and left turns onto the major street are the most hazardous (possibly because of the need to select a gap from two directions of oncoming traffic). Left turns from the major street are less hazardous than the minor street movements, and right-turn movements are the least hazardous.
  - Crash rates and the frequency of serious crashes are typically lower at restricted access intersections (3/4 design and right in/out) than at similar 4-legged intersections. Prohibiting/preventing movements (especially the crossing movement) at an intersection will likely result in a substantial crash reduction.
  - Minnesota crash data clearly supports the notion that reducing conflicts, especially crossing conflicts, is associated with a reduction in crashes. Equivalent information about the effects on crash severity has not been generated. However, it appears reasonable to assume that any effort that prevents crossing maneuvers that contribute to right angle collisions should also reduce severity of any remaining crashes.

Intersections – Conflict Points New Design





	Crossing	Turning	Merge/ Diverge	Total	Typical Crash Rate (crashes per mil. entering vehicles)
Full Access	4	12	16	32	0.7 [(1)]
Indirect Left Turn	0	4	20	24	0.1 [(2)]

[(1)] 2010-2012 rural MN state highway intersection crash data

2013 MnDOT Crash Data Toolkit

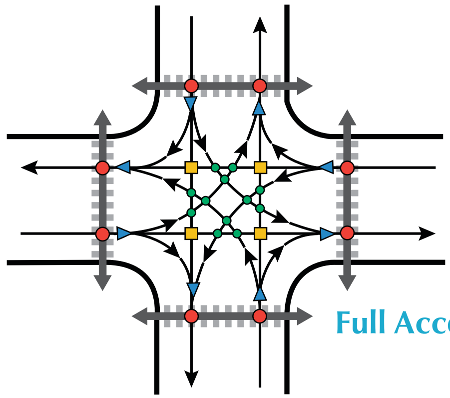
[(2)] Estimated based on a limited sample of MnDOT data

Highlights

- Analysis of crash data proves that the most frequent type of severe intersection crash is a right angle – vehicle maneuvers that involve crossing conflicts.
- In response to this data, highway agencies are beginning to implement intersection designs that reduce or eliminate the at-risk crossing maneuvers by substituting lower-risk turning, merging and diverging maneuvers. Two examples of these new designs include roundabouts and indirect turn treatments.
- The concept of indirect turns has primarily been applied to divided roadways where there is sufficient room in the median to construct the channelization necessary to restrict crossing maneuvers and to accommodate U-turns. This design technique has been implemented at approximately a dozen intersections in Maryland and North Carolina and, as a result, is considered Tried. However, before/after studies at these locations have documented close to a 90% reduction in total crashes and a 100% reduction in angle crashes. More information about indirect turns can be found in Report 650: *Median Intersection Design for Rural High Speed Divided Highways*. Minnesota has now constructed the indirect left turn design at expressway intersections along TH 36, TH 53, TH 65, TH 71, TH 169 and TH 212. Follow-up evaluations found overall crash reductions of approximately 75% and a 100% reduction in both angle and serious injuries.

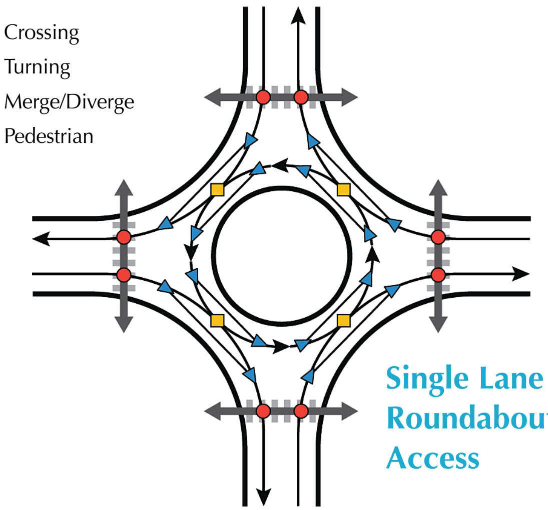
Intersections – Conflict Points

New Design



Full Access

- Crossing
- Turning
- Merge/Diverge
- Pedestrian



Single Lane Roundabout Access

Multi-Lane Roundabout

Full Access Typical Crash Rate 0.7 – Average crash rate for high volume/low speed signalized intersection

	Crossing	Turning	Merge/ Diverge	Total	Typical Crash Rate (crashes per mil. entering vehicles)
Full Access	4	12	16	32	0.7 [1]
Single Lane Roundabout	4	0	16	20	0.3 [3]
Multi-Lane Roundabout	N/A	N/A	N/A	N/A	1.4 [3]

[1] 2010-2012 rural MN state highway intersection crash data.

[2] NCHRP 15–30 Preliminary Draft

[3] Estimated based on a limited sample of MnDOT data

Note: Count of conflicts in dispute, although there are many.

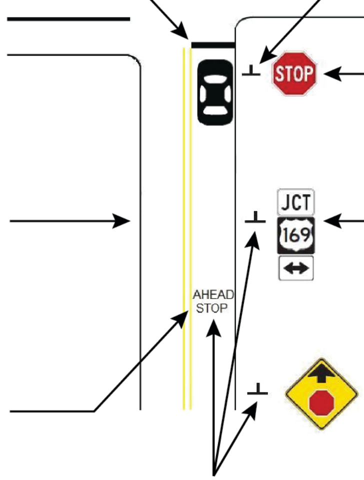
N/A – Not Available

2013 MnDOT Crash Data Toolkit

Highlights

- Roundabouts have been implemented at a sufficient number of intersections in Minnesota and around the country, such that follow-up studies have documented a Proven effectiveness of reducing both the frequency and severity of crashes. More information regarding roundabouts can be found in *Roundabouts: An Informational Guide* (Report No. FHWA-RD-00-067) at **www.tfhrc.gov/safety/00-0675.pdf**.
- Based on the observed safety and operational benefits documented at single lane roundabouts, highway agencies have begun to implement multi-lane roundabouts at several high-volume intersections to replace traditional traffic signal control. Studies of these installations indicate that, similar to single lane roundabouts, multi-lane roundabouts improve traffic operations and reduce intersection delay. However, it has been determined that multi-lane roundabouts have a greater number of conflicts than single lane design (current research has not been able to agree on the exact number) and this appears to have resulted in an increase in the number of property damage and minor injury crashes and have a crash rate almost twice the average for high volume/ low speed signal-controlled intersections in Minnesota.
- Research documented in FHWA's CMF Clearinghouse is consistent with Minnesota's experience with conflict reduction efforts resulting in crash reduction. The CMF Clearinghouse indicates the conversion to a single lane roundabout has a crash reduction factor (CRF) in the range of 25% to 65% for all severities and approximately 85% for severe crashes. This research also indicates that conversion to a multi-lane roundabout has resulted in an overall increase in crashes but the CRF for severe crashes is still in the range of 60% to 70%.

Intersections – Enhanced Signs and Markings



Mn MUTCD

Prioritized/ Phasing

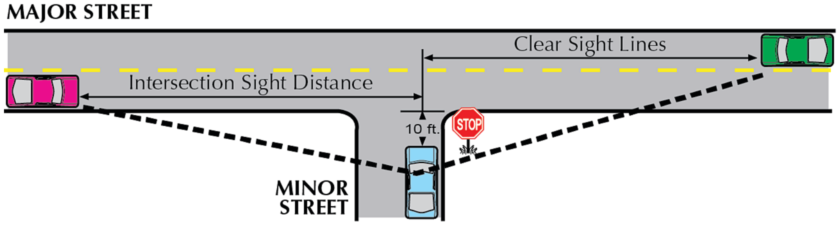
1. **Stop bar**
2. **Stop sign**
3. **Junction sign**
4. **Stop Ahead Message**
5. **Stop Ahead Sign**

Highlights

- The most common type of crash at STOP-controlled intersections is a right angle crash.
- Research performed in Minnesota (*Reducing Crashes at Controlled Rural Intersections – MnDOT No. 2003-15*) found that approximately 60% of these angle crashes involved vehicles on the minor road stopping and then pulling out and 26% involved vehicles running through the STOP sign.
- This same study also found that increasing the conspicuity of traffic control devices by using bigger, brighter, or additional signs and markings (such as the STOP AHEAD message and a STOP bar) are associated with decreasing Run the STOP crashes.
- A more recent report, *Safety Evaluation of STOP AHEAD Pavement Markings* (FHWA-HRT-08-043), documents the effects of adding STOP AHEAD pavement markings. The study looked at 175 sites in Arkansas, Maryland, and Minnesota. The study found crash reductions in the range of 20% to 40%, benefit/cost ratios greater than 2 to 1, and concluded that this strategy has the potential to reduce crashes at unsignalized intersections.

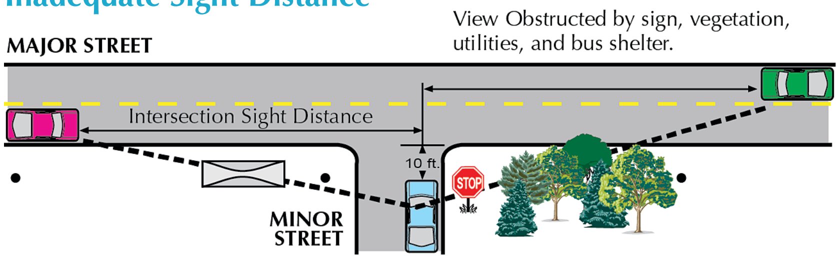
Intersections – Sight Distance

Adequate Sight Distance



Speed (mph)	30	35	40	45	50	55	60	65
Intersection Sight Distance	325 ft 7 sec.	400 ft 8 sec.	475 ft 8 sec.	550 ft 8 sec.	650 ft 9 sec.	725 ft 9 sec.	880 ft 10 sec	950 ft 10 sec

Inadequate Sight Distance



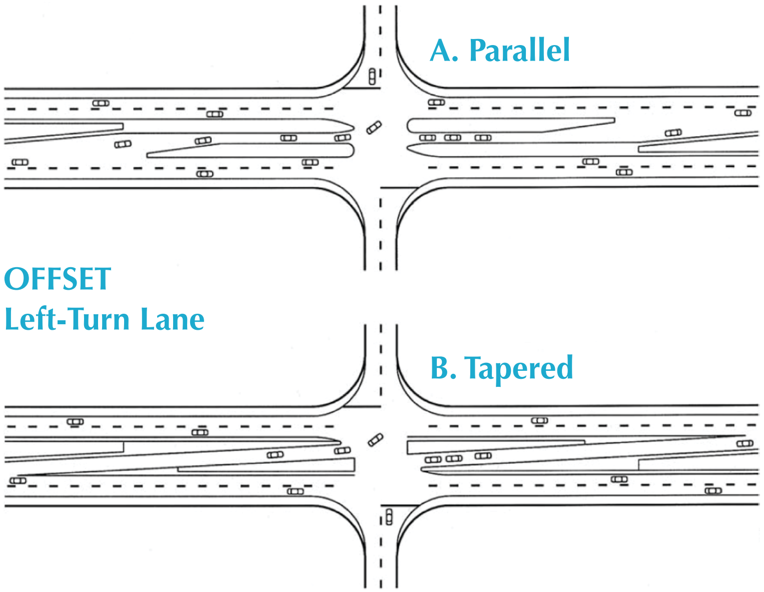
NCHRP Report 383 - Intersection Sight Distance
Iowa Highway Safety Management System, and AASHTO Green Book

Highlights

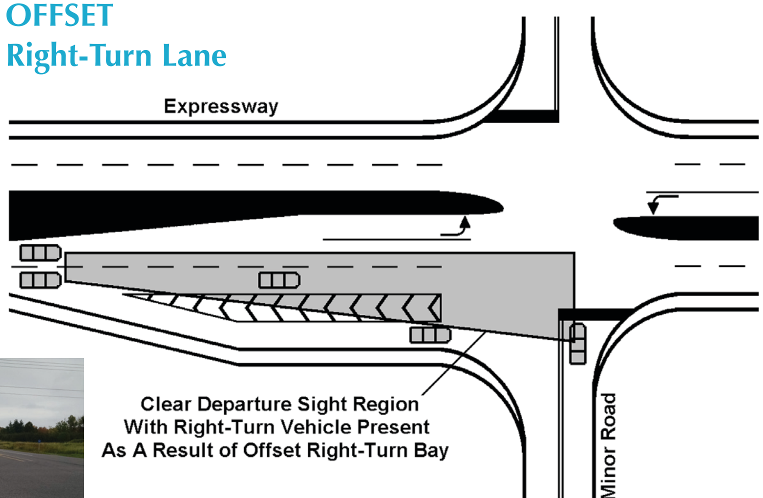
- Intersection sight distance refers to the length of the gap along the major roadway sufficient to allow a minor street vehicle to either safely enter or cross the major traffic system.
- A reasonable intersection sight distance allows for adequate driver perception reaction time (2.5 seconds) and either sufficient time to clear the major street, or to turn onto the major street and accelerate to the operating speed without causing approaching vehicles to reduce speed by more than 10 mph.
- The actual length of the recommended intersection distance is a function of the major street operating speed. However, the desired size of the gap varies from 7 seconds at 30 mph to 10 seconds at speeds of 60 mph and above.
- When dealing with MnDOT's trunk highways, refer to Section 5-2.02.02 of the *Road Design Manual* for additional guidance regarding intersection sight distance.
- It is important to note that intersection sight distance is always greater than stopping sight distance, by as much as 30% to 60%.
- The 10-second "Rule of Thumb" – 10 seconds of intersection sight distance – is a good estimate, regardless of conditions.
- Removal of vegetation and on-street parking are cost-effective safety improvements for intersections.

Intersections–Turn Lane Designs

OFFSET Left-Turn Lane



OFFSET Right-Turn Lane

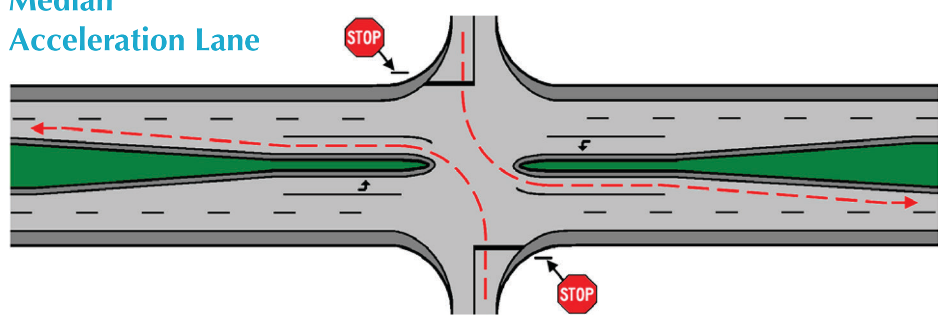


NCHRP 15-30 Preliminary Draft

Highlights

- Providing right and left turn lanes at intersections are included in Minnesota's list of high priority strategies.
- However, there are locations where vehicles are stopped or decelerating in the turn lane and can block the line of sight for other vehicles waiting at the intersections. In these cases, the use of offset left and right turn lanes will improve the line of sight for vehicles waiting to complete their crossing or turning maneuvers.
- Offset turn lanes are considered Tried (as opposed to Proven). A before/after study of offset left turn lanes in North Carolina reported a 90% reduction in left turn crashes. A similar study of offset right turn lanes in Nebraska found a 70% reduction in near-side right angle crashes.
- The Median Acceleration Lane (MAL) has been used at a number of locations in Minnesota and is also considered Tried. Before/after studies indicate a 75% reduction in same direction sideswipe crashes, a 35% reduction in far-side right angle crashes, and a 25% reduction involving left turn crashes from the minor road.
- Turn lane length – new report #2010-25, *Base Turn Lane Length on Analysis of Deceleration and Storage Demand.*

Median Acceleration Lane

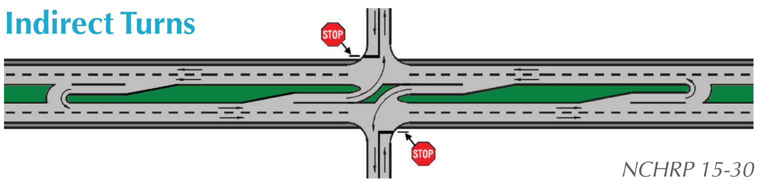


Intersections – Roundabouts and Indirect Turns

MnDOT Metro District
Before: After Study

Minnesota Trunk Highway 13 at Scott County Highway 2

Indirect Turns



NCHRP 15-30

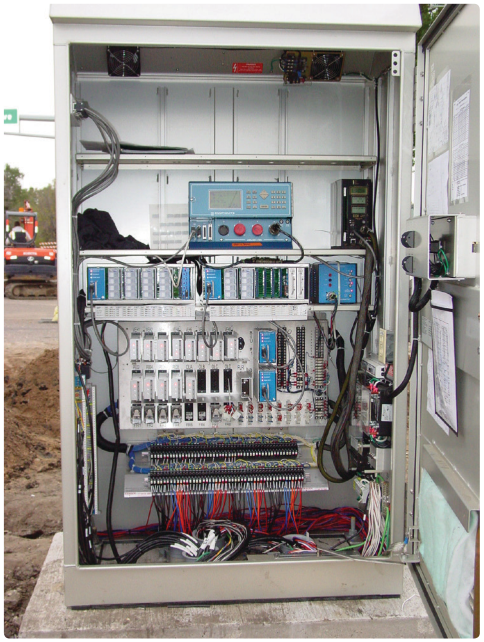
Partial T-Interchange

Photo provided by TKDA

Highlights

- The most common and most severe type of crash at STOP-controlled intersections is a right angle which involves a vehicle on the minor road attempting to select a safe gap along the major highway in order to cross.
- A proven strategy to reduce gap selection-related angle crashes involves redesigning the intersection or median crossover to eliminate crossing conflicts (which have the highest probability of a crash) by substituting merging, diverging, or turning conflicts (which have a lower probability of a crash).
- The primary examples of reduced-conflict designs at four-legged intersections include roundabouts and indirect turns.
- Roundabouts are considered to be Proven effective (there is virtually no possibility of an angle crash) with statistically significant crash reductions – 38% for all crashes, and 76% for injury crashes and for serious injury and fatal crashes. Not withstanding the superior safety performance, care must be taken when considering conversion to a roundabout – implementation costs are in the range of $1,000,000 (rural) to $5,000,000 (urban) and all entering legs are treated equally. The key question is do the traffic characteristics and function classification support the degrading of main-line traffic operations.
- The concept behind indirect turns is that merge, diverge, and turning conflicts result in fewer and less severe crashes than crossing conflicts. An example of the indirect turn applied to a divided roadway is the J-turn. This application involves constructing a barrier in the median crossover and forcing minor street crossing traffic to instead make a right turn, followed by a downstream U-turn, followed by another right turn. J-turns have been Tried at about a dozen locations in Maryland and North Carolina. Implementation costs are in the range of $500,000 to $750,000, and a preliminary crash analysis found a 100% reduction in angle crashes and a 90% reduction in total crashes.
- At T intersections three new design concepts have been developed: the partial T-interchange, the continuous green T, and the diverging diamond interchange.
- The partial interchange is an interesting concept for T intersections along divided roadways – the construction of one bridge on the "near-side" of the intersection eliminates all crossing maneuvers. This concept is being considered for several locations in Minnesota, but deployment has not been sufficiently wide spread to be able to identify typical implementation costs or document crash reductions.

Intersections–Traffic Signal Operations



Highlights

- Installing traffic signals is NOT considered to be a high priority intersection safety strategy because of the results of studies done nationally and in Minnesota. At most intersections, the installation of a traffic signal will increase the number of crashes, along with increasing crash and severity rates. Also, as a category, signalized intersections have a higher average crash density, crash rate, and severity rate than the average for STOP-controlled intersections.
- However, if a traffic signal must be installed to address intersection delay and congestion, there are several suggested high priority strategies to reduce frequency and severity of intersection crashes. These include:
  - Use of multiphase signal operation combined with left turn lanes
  - Provide a coordinated signal system along urban arterials
  - Use overhead indications – one per through lane mounted at the center of each lane
  - Provide dilemma zone protection and optimize clearance intervals
  - Use advance warning flashers to supplement static signs where a signal may be unexpected
  - Pedestrian indications including the use of count down timers

Intersections – Red Light Enforcement

Highlights

- Red Light Running (RLR) is a safety issue across the country. In 2009, RLR resulted in 676 traffic fatalities (10% of all intersection-related fatalities). In addition, the Insurance Institute for Highway Safety estimates that 130,000 people were injured in crashes in 2009 due to RLR.
- RLR has also been found to be an important safety issue in Minnesota. In the Minneapolis-St.Paul Metropolitan Area, approximately 60% of severe crashes are intersection related, approximately 50% of those occur at intersections controlled by traffic signals, and almost one-half of these involve a right angle collision.
- In the metropolitan area, the number of severe right angle crashes varies among state, county and city intersections, but one fact is consistent – along each system, right angle crashes result in more fatalities and serious injuries than rear-end, left-turn and right-turn crashes combined.
- Published research suggests that initial steps to address right angle crashes at signal-controlled intersections involve checking clearance (Yellow and All-Red) intervals and signal hardware (overhead indications, 12-inch lenses, and back plates provide better visibility for drivers).
- A review of Minnesota crash data indicates that the use of "good" clearance intervals and signal hardware is not enough to prevent right angle crashes.
- Intersections with these features have (on average) a higher density of severe crashes than intersections with only pedestal mounted signals with 8-inch lenses.
- This data suggests that additional enforcement efforts are required to address driver behavior. An American Automobile Associations survey in 2010 found that more than 30% of respondents admitted to running a red light in the previous 30 days when they could have safely stopped.

MINNESOTA DEPARTMENT OF TRANSPORTATION

Intersections – Red Light Enforcement

Highlights

- Discussions with a variety of law enforcement officers has found that RLR enforcement has not been a priority. This is primarily due to the fact that it takes two officers to do it safely – one on the approach to observe the violation and one past the intersection to issue the ticket – and most agencies do not have enough officers to devote this level of effort at a single location.
- Nationally, the solution to law enforcement staffing levels has been the use of red light cameras. Studies of effectiveness of cameras has documented an 80% reduction in all crashes, a 75% reduction in angle crashes, and a 60% reduction in RLR-related crashes. The studies also found that cameras may increase rear-end crashes, but they tend to be less severe.[1]
- In Minnesota, red light cameras are not allowed by state law. As a result, a number of agencies (City of Burnsville, Olmstead County, and MnDOT) have implemented an alternative, low-cost (typically less than $2,000 per intersection) technique to assist law enforcement efforts to reduce RLR – the use of confirmation lights.
- These small blue lights are mounted on the side or the back of traffic signal supports and are wired in parallel with the signal so that when the signal displays a red indication, the confirmation light illuminates at the same time. The use of confirmation lights allows a single officer past the intersection to both observe a violation and safely apprehend the violator.
- Studies of effectiveness of confirmation lights have documented crash reductions between 30% and 47% in Florida. In Minnesota, the installations are too new and too few to be able to document a reduction in crashes. However, a study of two installations in Burnsville found a 50% reduction in the number of violations.[2]

[1] *Toolbox of Countermeasures to Reduce Red Light Running*, Midwest Transportation Consortium, InTrans 10-386

[2] Unpublished Technical memorandum prepared by SEH (Thomas Sohrweide) and provided by the City of Burnsville

Rural Intersections – Safety
Effects of Street Lighting

System-Wide Comparative Analysis				
Item	Intersections without Street Lights	Intersections with Street Lights	Reduction	Statistical Significance
Intersections	3236	259		
Night Crashes	34%	26%	26%	Yes
Night Crash Rate	0.63	0.47	25%	Yes
Night Single Vehicle Crashes	23%	15%	34%	Yes
Night Single Vehicle Crash Rate	0.15	0.07	53%	Yes

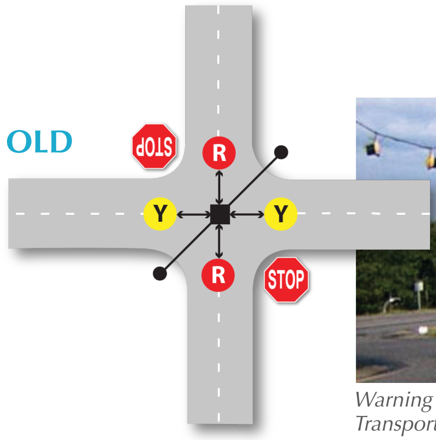
Before vs. After Crash Analysis				
Item	Before	After	Reduction	Statistical Significance
Intersections	12	12		
Number of Night Crashes	47	28	40%	Yes
Night Crashes/Intersection/Year	1.31	0.78	40%	
Total Crashes/Intersection/Year	2.44	2.08	15%	
Night Crash Rate	6.06	3.61	40%	Yes
Total Crash Rate	2.63	2.24	15%	Yes
Severity Index	43%	32%	26%	Yes
Night Single Vehicle Crash Rate	4.0	2.84	29%	Yes
Night Multiple Vehicle Crash Rate	2.06	0.77	63%	Yes

MN/RC-1999-17

Highlights

- The installation of street lights is considered to be a Proven effective strategy for reducing crashes.
- Research has found that the installation of street lights at rural intersections reduced:
  - Night crashes by 26% to 40%
  - Night crash rate by 25% to 40%
  - Night single vehicle crashes by 29% to 53%
  - Night multiple vehicle crashes by 63%
  - Night crash severity by 26%
- A benefit/cost analysis found that the crash reduction benefits of street lighting at rural intersections outweigh costs by a wide margin. The average B/C ratio was about 15:1.
- The results of recent case study research suggests that the use of street lighting is more effective at reducing night crashes than either rumble strips or overhead flashers.
- A survey of practice among Minnesota counties found typical lighting installation costs along county facilities in the range of $1,000 to $5,000 per intersection and annual operations maintenance costs in the range of $100 to $600 per light.

Rural Intersections – Flashing Beacons



Warning Flashers at Rural Intersection, Minnesota Department of Transportation Final Report No. 1996-01. 1997

Highlights

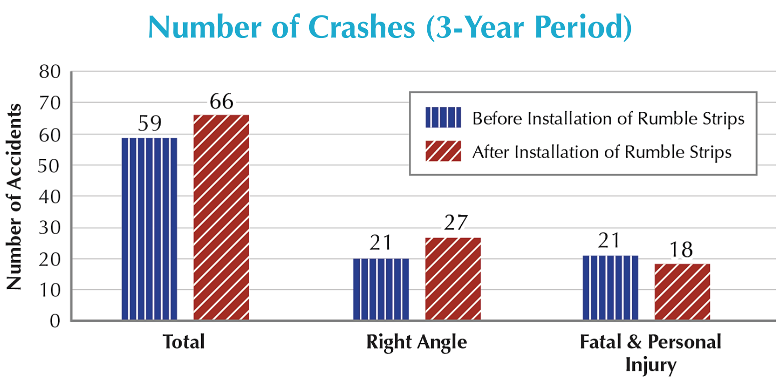
- A review of historic crash data indicated that STOP-controlled rural intersections with overhead flashers had higher average crash rates than comparable intersections without overhead warning flashers.
- Anecdotal information that surfaced during the investigation of several fatal crashes indicated that some drivers were mistaking Yellow/Red warning flashers for Red/Red flashers that would indicate an All-Way STOP condition.
- In order to address the issue of effectiveness, MnDOT commissioned a study by the University of Minnesota's Human Factors Research Lab[1]. The study resulted in the following conclusions:
  - About one-half of drivers surveyed understood the warning intended by the flasher, but most did not adjust their behavior.
  - About 45% of the drivers misunderstood the intended message and thought it indicated an All-Way STOP condition.
  - The change in crash frequency at a sample of intersections was NOT statistically significant.
  - In response to this research, MnDOT has been removing overhead flashers.
- Where there is evidence that additional intersection warning is necessary, options include – use of red flashers on STOP signs, advance warning flashers on STOP AHEAD signs, and flashing LEDs on the STOP sign. It should be noted that the follow-up studies on effectiveness of the flashing LEDs found a 42% reduction in right angle crashes but concluded that too few crashes made the results statistically unreliable.[2]
- Another strategy that has been used at rural intersections identified as a candidate for safety investment based on either an unusual frequency of severe crashes or through a systemic risk assessment involves the use of dynamic mainline warning signs. A flasher on the advance warning sign is activated when there is a vehicle on the minor road waiting at the STOP sign to enter the intersection. Follow up studies have documented a reduction in crashes, but there has not yet been enough installations or studies of the dynamic warning system to be considered proven effective.

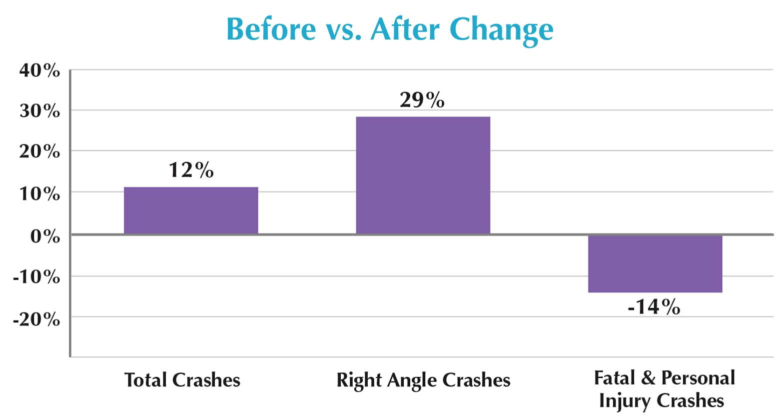
Dynamic Mainline Warning Sign

[1] MN/RC – 1998/01, *Warning Flashers at Rural Intersections,* Stirling Stackhouse, Ph.D., University of Minnesota Human Factors Research Laboratory

[2] MnDOT LRRB Report 2014-02, *Estimating the Crash Reduction and Vehicle Dynamic Effects of Flashing LED Stop Signs,* Gary Davis, University of Minnesota

Rural Intersections – Transverse Rumble Strips



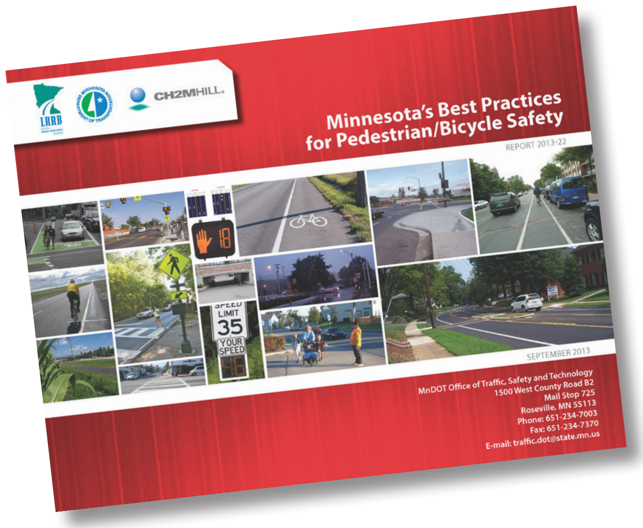


MnDOT's Transportation Synthesis Report, TRS 0701, August 2007

Highlights

- The use of transverse rumble strips to address safety issues at rural intersections has been part of the traffic engineer's tool box for many years. However, studies on implementation have demonstrated mixed results.
- MnDOT took the opportunity to perform a thorough study of transverse rumble strips as part of preparing their defense in a lawsuit alleging negligence on the state's part for not having rumble strips at a particular intersection. The study resulted in the following conclusions:
  - The results of previous research documented mixed results, with some studies showing modest improvement and others showing an increase in crashes. The largest study, basically statewide along secondary roads, showed an overall increase in crashes at the intersections where the rumble strips were installed.
  - A before/after analysis of 25 rural intersections in Minnesota found that total intersection crashes and right angle crashes actually increased after installing rumble strips. The number of fatal plus injury crashes declined slightly; however, none of the changes were statistically significant.
- A project by the University of Minnesota's Human Factors Research Lab found that rumble strips had a minor effect on driver behavior relative to speed reduction and breaking patterns. However, there was no evidence of crash reduction.
- For more information, see MnDOT's *Transportation Synthesis Report, TRS 0701* (**www.lrrb.org/trs0701.pdf**).
- Strategies that have been proven effective at improving safety at rural Thru/STOP intersections include enhanced signs, markings (C-28), and street lights (C-35).
- The relative ineffectiveness of transverse rumble strips may be due to the fact that the majority of crashes at thru/STOP controlled intersections involve vehicles that have stopped and then proceed into the intersection. These crashes are attributed to gap selection as opposed to intersection recognition.
- If an investigation of crashes at a rural intersection indicates multiple run-the-stop crashes, the installation of transverse rumble strips can be considered. However, if there are any homes in the immediate vicinity consideration should also be given to strategies that won't generate noise complaints.

Pedestrian Safety Strategies



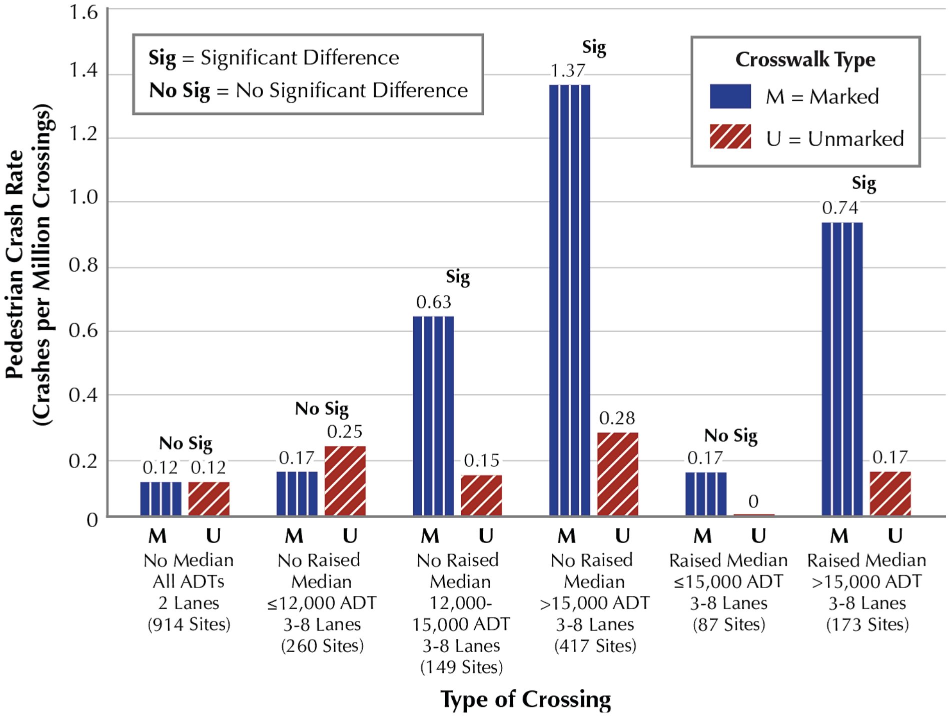
	Strategies	Pages	Crash Reduction/ Crash Features	Proven/Tried/ Experimental	Operational Effects (Mobility)	Candidate Locations	Design Features	Construction Costs
Pedestrian Safety Strategies	Sidewalks	1-2	50 to 90% reduction in "walking in roadway" pedestrian crashes	Proven	N/A	Urban arterials & collectors	Curb ramps, cross slope, buffer zones	$4 to $5 per square foot
	Crosswalks and Crosswalk Enhancements	3-8	Varies	Proven/Tried	N/A	Intersections	Should be part of package including crosswalk enhancements	$200 per crosswalk
	Medians and Crossing Islands	9-10	39 to 46%	Proven	May provide operational benefits	Wide 2-lane roads and multi-lane roadways	4 to 8 feet wide	$15,000 to $30,000 per 100 feet
	Curb Extensions	11-12	39 to 46%	Proven	Potential reduction in speeds	Urban arterials and collectors with curb parking	Roadway with parking or shoulder	$5,000-$10,000 per extension
	Pedestrian Hybrid Beacon System	13-15	60%	Tried	Additional delay for vehicles stopping for pedestrians	Mid-Block Crosswalk locations — Not at intersections	Pedestrian activated	$80,000
	Rectangular Rapid Flashing Beacon	16-17	78 to 100% yield to pedestrian rate	Tried	Additional delay for vehicles stopping for pedestrians	Mid-Block Crosswalk	Passive or active pedestrian activation	$10K to $15K
	Crosswalk Lighting	18-19	33 to 44%	Proven	N/A	Isolated crosswalks not along a continuously lit roadway	Require a power source	$10k to $25K per intersection
	Traffic Signals	20-22	Leading Pedestrian Interval — 60%	Tried	Increases delay and reduces mobility of major roadway	Intersections that meet signal warrants	Short cycle lengths, countdown timers, easy accessibility	New Signal - $175,000 to more than $300,000 per intersection

Highlights

- Fatal crashes involving pedestrians are one of AASHTO's Safety Emphasis Areas. In the U.S., there are about 5,000 pedestrians killed each year, which represents about 11% of all traffic fatalities.
- Minnesota averages about 37 pedestrian fatalities annually (about 9% of total traffic fatalities). The involvement rate (0.4 pedestrian fatalities per 100,000 population) ranks 47th – only Rhode Island, New Hampshire, and Idaho have a lower rate.
- Nationally, fatal pedestrian crashes most often occur in urban areas (67%), away from intersections (58%), and during good weather (85%). Over two-thirds of the pedestrians killed are male.
- The most common pedestrian activities associated with fatal crashes are walking/working in the road and crossing the roadway.
- Contributing factors associated with motor vehicle drivers include failure to yield right of way (35%) and driver inattention/distraction (21%).
- To better assist agencies in addressing pedestrian and bicycle safety concerns, MnDOT prepared *Minnesota's Best Practices for Pedestrian/Bicycle Safety*. The document identifies 19 common safety strategies, including crosswalk enhancements, new technologies, road diets, and speed reduction measures. A description is provided for each strategy, along with an overview of safety benefits, typical characteristics of candidate location, implementation costs, and a statement of what constitutes a "best" practice.
- Another resource that can provide assistance in developing pedestrian crossings is MnDOT Report 2014-21: Uncontrolled Pedestrian Crossing Evaluation Incorporating Highway Capacity Manual Unsignalized Pedestrian Crossing Analysis Methodology. This report provides an overview of previous safety research and presents a methodology for estimating the delay that a pedestrian would experience waiting for a safe gap in traffic based on roadway width and traffic volumes. Locations with short wait times would be considered low-priority candidates for crosswalk development and locations with long wait times would be high-priority candidates.

Pedestrian Safety – Crash Rates vs. Crossing Features

Charles V. Zegeer, et al., Safety Effects of Marked vs. Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines, 1996-2001 (www.walkinginfo.org/pdf/r&d/crosswalk_021302.pdf)



Highlights

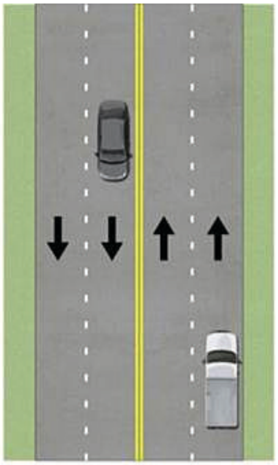
- Three of the more common strategies intended to address pedestrian crashes include reducing vehicle speeds, providing a marked crosswalk, and installing a traffic signal.
- The research is abundantly clear – merely changing the posted speed limit has never reduced vehicle speeds, painting crosswalks at unsignalized intersections is actually associated with higher frequencies of pedestrian crashes, and installing a traffic signal has never been proven effective at reducing pedestrian crashes.
- Reducing vehicle speeds is associated with reducing the severity of a pedestrian crash, but actually reducing speeds requires changing driver behavior, which requires changing the roadway environment. Strategies that have demonstrated an effect on driver behavior include vertical elements (speed bumps and speed tables), narrowing the roadway (converting from a rural to an urban section), and extraordinary levels of enforcement.
- A cross-sectional study of 2,000 intersections in 30 cities across the U.S. found that marked crosswalks at unsignalized intersections are NOT safety devices. The pedestrian crash rate was higher at the marked crosswalks and this effect is greatest for multilane arterials with volumes over 15,000 vehicles per day.
- A before/after study at over 500 intersections in San Diego and Los Angeles found a 70% reduction in pedestrian crashes following the removal of marked crosswalks at uncontrolled intersections.
- Traffic signals have not proven to be effective at reducing pedestrian crashes – the highest pedestrian crash frequency locations in most urban areas are signalized intersections.
- Observations of pedestrian behavior at traffic signals suggests that there is a low level of understanding of the meaning of the pedestrian indications and a high level of pedestrian violations – very few push the call button and fewer yet wait for the walk indication.

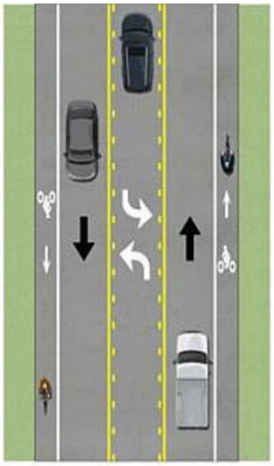
Pedestrian Safety – Curb Extensions and Medians

Median Refuge Near Intersection

Curb Extensions and Sidewalks

4-Lane Road



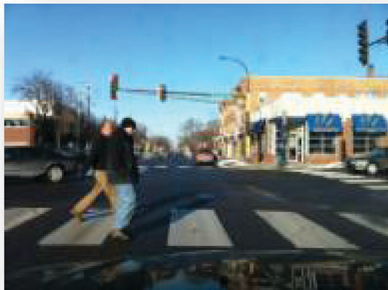


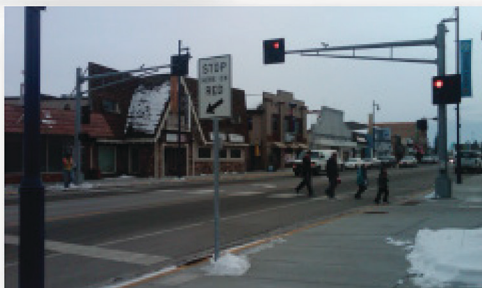
Road Diet (3 Lanes)

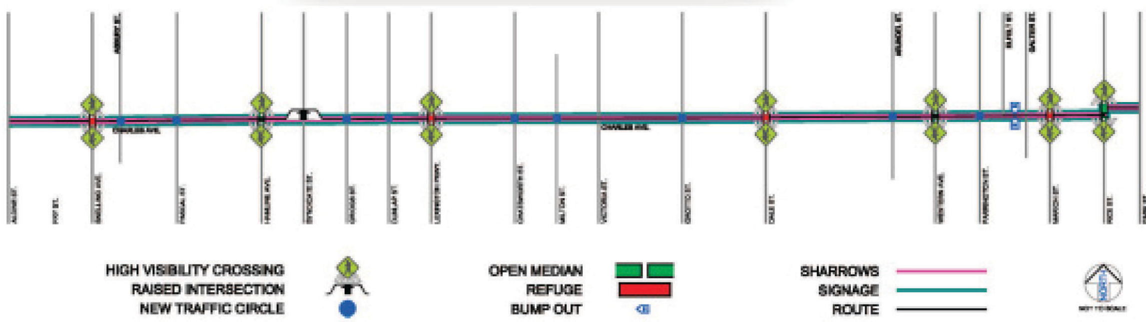
Highlights

- Pedestrian strategies that have proven to be effective include the following:
  - **Overpass** (in order to be effective, crossing the roadway at-grade must be physically prevented)
  - **Street Lighting**
  - **Refuge/Median Islands** – Reduces vehicle speeds at pedestrian crossing locations or intersections.
  - **Curb Extensions** – Reduces potential vehicle conflicts by reducing pedestrian crossing distance and time, and improves lines of sight.
  - **Sidewalks**
  - **Road Diets** (converting four-lane undivided roads to a three-lane cross-section) – Eliminates the multi-vehicle threat that can occur on four-lane roads.

Pedestrian/Bike Strategies







Highlights

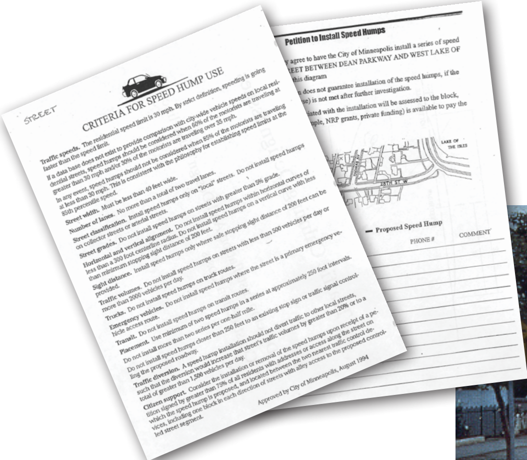
- Some more recent pedestrian and bicycle strategies include:
    - **Countdown Timers** – Countdown timers are flashing timers, usually installed with pedestrian indication lights, which provide the number of seconds remaining during the pedestrian phase.
    - **Leading Pedestrian Interval** – A leading pedestrian interval provides the pedestrian walk 2 or 3 seconds ahead of the vehicle green, allowing pedestrians a head start and the ability to enter the crosswalk before right-turning vehicles can turn into the crosswalk.
    - **HAWK Signals** – Should only be used in conjunction with a marked crosswalk and typically not at an intersection
    - **Bike Boulevards** – still considered experimental – however, one study looking at seven bike boulevards in Berkeley, found a 60% reduction in bicycle-involved crashes.

Complete Streets

Highlights

- Complete Streets is a transportation network approach, involving the provision of safe access for all street users, that must be considered during the planning and design phases of all roadway improvement projects. Complete Streets is neither proscriptive nor a mandate for an immediate retrofit; it is however, intended to be reflective of local needs and to serve adjacent land uses.
- MnDOT has a policy that requires the principles of Complete Streets to be considered on trunk highways at all phases of planning and project development in order to establish a comprehensive, integrated, and connected multimodal transportation system.
- A good phrase to summarize the need to determine the right locations to implement pedestrian and bicycle amenities is as follows: "Not all modes on all roads, right mode on right road."
- MnDOT's State Aid bicycle guidelines have been modified to allow designers greater flexibility in order to be able to fit bicycle facilities into constrained cross-sections found along existing roadways.

Neighborhood Traffic Control Measures



CRITERIA FOR SPEED HUMP USE

Petition to Install Speed Humps

ITE Traffic Calming Seminar

Table 8.3. General Warrants. (Sarasota, FL)

Warrant	Major Collectors	Minor Collectors	Local Residential Streets
1. Minimum traffic volume	>8,000 vpd or 800 vph	>4,000 vpd or 400 vph	>1,000 vpd or 100 vph
2. Anticipated cut-through traffic	50%	40%	25%
3. 85th percentile speed	10 mph > speed limit	10 mph > speed limit	> speed limit
4. Pedestrian crossing volume	>100 per hour	>50 per hour	>25 per hour
5. Accidents per year	6	6	3

vpd = vehicles per day; vph = vehicles per hour
Source: Engineering Department, City of Sarasota, FL.

Table 8.4. Speed Hump Warrants. (Montgomery County, MD)

Criterion	Original	Interim	Present
Minimum volume	60 vph	100 vph	100 vph
Minimum 85th percentile speed Secondary street Primary street	31 mph 34 mph	31 mph 31 or 36 mph (depending on speed limit)	32 mph 34 or 39 mph (depending on speed limit)
Minimum length of segment	None	1,000 feet	1,000 feet
Resident concurrence	67%	80% on treated street	80% on treated street 50% on side streets

vph = vehicles per hour; mph = miles per hour
Source: Department of Public Works and Transportation, Montgomery County, MD.

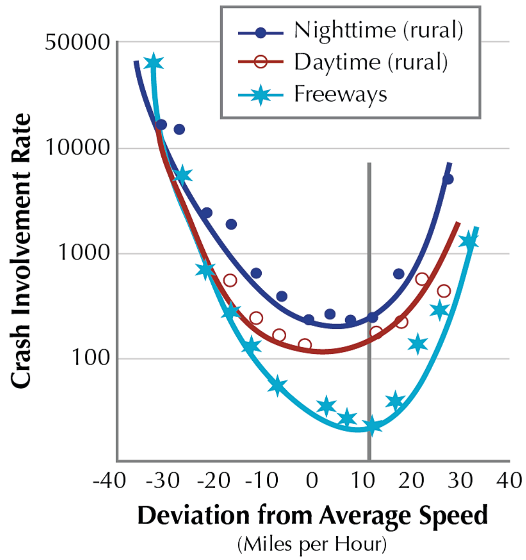
ITE, Traffic Calming - State of the Practice

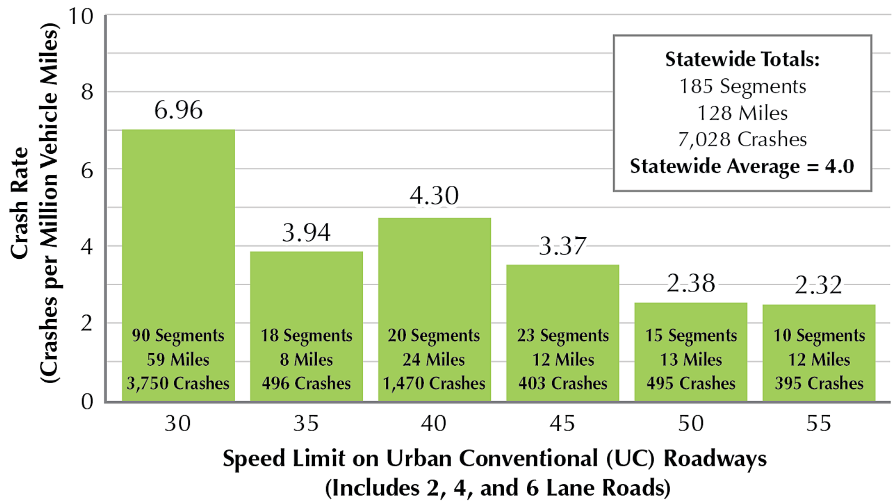
Highlights

- Neighborhood traffic control (traffic calming) usually involves applying design techniques and devices on local streets in order to modify driver behavior and traffic characteristics.
- The application of these devices are usually limited to residential streets, have been infrequently used on residential collectors, and should not be considered on arterials due to the presence of transit vehicles, trucks, and emergency responders.
- Typical techniques involve the use of signs, markings, road narrowing or diverters, vertical elements, and the use of technology to increase the enforcement presence.
- A few studies of the effectiveness of these devices have been conducted – the general conclusions are:
  - Speed humps/bumps are moderately effective at lowering speeds in the range of 3 to 7 mph in the immediate vicinity of the device. However, speeds between the devices have been observed to increase. It should also be noted that these devices are NOT allowed on any state-aided street or highway.
  - Adding STOP signs lowers speeds by about 2 mph, in the vicinity of the STOP sign, but also reduces compliance – a greater number of drivers completely disregard the sign than come to a complete stop. In addition, speeds in the segments between STOP signs have been observed to increase as drivers attempt to make up for lost time. One further point should be considered when evaluating the possibility of adding STOP signs for speed management - research has shown that low volume intersections with STOP control have a higher frequency of crashes than uncontrolled intersections.
  - Changing speed limit signs has never changed driver behavior.
  - Enforcement does change driver behavior - but the halo effect of enforcement may be as small as a few minutes, so a sustained effort is required.

www.ite.org/traffic/tcstate.asp

Speed Zoning





"Statistical relationship between vehicular crashes and highway access" Report: MN/RC–1998–27

Highlights

- There are two basic types of speed zones in Minnesota:
    1. Statutory speed limits established by the legislature – 30 mph on city streets, 55 mph on rural roads, 65 mph on rural expressways, and 70 mph on rural interstates.
    2. Speed zones established based on the results of an engineering study of a particular roadway. The legislature has assigned the responsibility for setting the speed limits in the zones to the Commissioner of Transportation.
- The premise underlying the establishment of speed limits is that most drivers will select a safe and reasonable speed based on their perception of the roadway's condition and environment. This has led to the practice of conducting a statistical analysis of a sample of actual vehicle speeds as part of a comprehensive engineering investigation.
- The two primary performance measures are:
    1. 85th percentile speed – The speed below which 85% of the vehicles are traveling.
    2. 10 mph pace – the 10 mph range that contains the greatest number of vehicles.
- Experience has shown that the most effective speed limits are those that are close to the 85th percentile speed and in the upper part of the 10 mph pace.
- The graph at the top of this page illustrates the relationship between vehicle speeds and crash rates. The data indicates that where vehicle speeds are in the range of 5 to 10 miles per hour above the average speed (which approximates the 85th percentile speed in most speed profiles) crash rates are the lowest.
- The graph at the bottom of this page illustrates the relationship between speed limit and average crash rates for urban highways on the State's system. This data indicates that in Minnesota crash rates go down as speed limits increase along urban highways.
- It should be noted that a similar relationship between speed limits and crashes is documented in the HSM. The same Minnesota research indicates that access density is a better predictor of urban crash rate than is the posted speed limit.

Speed Zoning

Speed Zoning Studies					
Study Location	Before	After	Sign Change +/- MPH	85% Before After	Change MPH
TH 65	SPEED LIMIT 40	SPEED LIMIT 30	-10	34 34	0
TH 65	SPEED LIMIT 50	SPEED LIMIT 40	-10	44 45	+1
Anoka CSAH 1	SPEED LIMIT 45	SPEED LIMIT 40	-5	48 50	+2
Anoka CSAH 24	SPEED LIMIT 30	SPEED LIMIT 45	+15	49 50	+1
Anoka CSAH 51	SPEED LIMIT 40	SPEED LIMIT 45	+5	45 46	+1
Hennepin CSAH 4	SPEED LIMIT 50	SPEED LIMIT 40	-10	52 51	-1
Noble Ave	SPEED LIMIT 30	SPEED LIMIT 35	+5	37 40	+3
62nd Ave N	SPEED LIMIT 35	SPEED LIMIT 30	-5	37 37	0
Miss. St	SPEED LIMIT 30	SPEED LIMIT 35	+5	39 40	+1

Minnesota Department of Transportation (MnDOT)

Highlights

- In Minnesota, state statutes assign the establishment of sped zones to the Commissioner of Transportation in order to achieve a consistency across all roads in Minnesota.
- Speed zones are established based on an analysis of existing vehicle speeds along a segment of roadway and a variety of other information including road cross-section, density of access, land use and other characteristics of the road environment.
- In a number of cases, local authorities have questioned the outcomes of the technical analysis and requested the posting of a lower speed limit. The table to the left illustrates the outcome of experiments that were conducted – the posted limits were changed and local agencies were invited to apply as much enforcement as staff levels would allow. The outcome was identical in all cases, driver behavior did not change.
- These experiments support the notion that a majority of divers pick a safe and comfortable speed based on their perception of the road environment and only changing the posted speed did not change their behavior.

Speed Reduction Efforts

Designing Roads That Guide Drivers to Choose Safety Speeds, Iran, J. & Garrick, N., Connecticut Transportation Institute, 2009

Summary of Impacts and Costs of Rural Traffic Calming Treatments

Treatment	Change in 85th Percentile Speed (mph)	Cost	Maintenance	Application
Transverse pavement markings [1]	-2 to 0	$	Regular painting	Community entrance
Transverse pavement markings [1] with speed feedback signs	-7 to -3	$$$	Regular painting	Community entrance
Lane narrowing using painted center island and edge marking	-3 to +4	$	Regular painting	Entrance or within community
Converging chevrons [1] and "25 MPH" pavement markings	-4 to 0	$	Regular painting	Community entrance
Lane narrowing using shoulder markings and "25 MPH" pavement legend	-2 to 4	$	Regular painting	Entrance or within community
Speed table	-5 to -4	$$	Regular painting	Within community
Lane narrowing with center island using tubular markers	-3 to 0	$$$	Tubes often struck needing replacement	Within community
Speed feedback sign (3 months after only)	-7	$$$	Troubleshooting electronics	Entrance or within community
"SLOW" pavement legend	-2 to 3	$	Regular painting	Entrance or within community
"35 MPH" pavement legend with red background (1)	-9 to 0	$	Background faded quickly; accelerated repainting cycle	Entrance or within community

[1] Experimental approval required per Section 1A.10 of MUTCD.

$ = under $2,500
$$ =$2,500 to $5,000
$$$ = $5,000 to $12,000

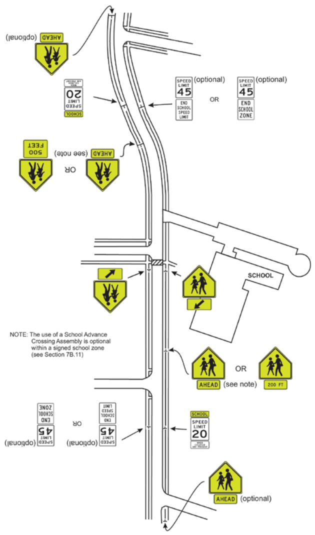
Traffic Calming on Main Roads Through Rural Communities, FHWA-HRT-08-067, Krammes, R., 2009

Highlights

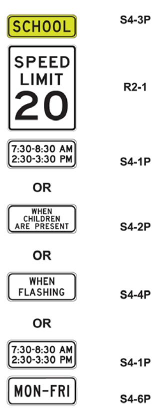
- Beyond merely changing the posted speed limit, efforts to change driver behavior have focused on two approaches – added enforcement (remember – electronic enforcement is not allowed in Minnesota) and making changes to the road environment in order to adjust driver perception.
- The use of added enforcement (be sure to check with your local police/sheriff to determine if they have the resources to provide a higher level of enforcement) produces a high level of consistency with the posted limit BUT only when the officers are present. The spillover ("Halo") effect of enforcement has been observed to be as little as a few minutes and rarely as long as a week.
- One approach to changing driver perception of speed involves adding pavement markings (to provide an illusion of speed), reinforcing pavement messages, vertical elements and dynamic signing. The results of these attempts (see table) have proven, in most cases, to be very limited.
- A second approach to changing driver perception involves reconstructing the roadway to add design elements that reinforce the notion of an urban environment and lower speeds that are typical in these areas. A typical operating speed on a two-lane suburban road is in the 40 to 45 mph range but on a similar two-lane urban road with curb, gutter, and sidewalk, the typical operating speed drops to around 30 mph.

Speed Zoning – School Zones

School Zone Signage Placement



School Speed Limit Signage



Minnesota Manual on Uniform Traffic Control Devices, January 2014

Highlights

- In 1975 the Legislature changed Minnesota Statute 169.14 to allow local authorities to establish speed limits in school zones. Key provisions of the law include: (A) Local authorities may establish a school speed zone based on the outcome of an engineering and traffic investigation, (B) School speed limits may not be lower than 15 miles per hour or more than 30 miles per hour below the established speed limit and (C) The school speed zone is defined as that section of street or highway that abuts school property or where there is an established school crossing with advanced school signs that define the area.
- Establishing a school speed zone on a state trunk highway requires the approval of the Commissioner of Transportation.
- The signs that are used to convey the message to drivers that they are approaching a school area and school speed zone include:
    - Advance School sign
    - School Zone Speed Limit sign
    - A variety of alternative plaques that describe when the school speed limit is in effect – times of the day, WHEN CHILDREN ARE PRESENT, or WHEN (an attached flasher is) FLASHING.
- Local authorities establishing a school speed zone should be aware that simply posting the signs designating a school speed zone does not guarantee that either a majority of drivers will actually lower their speed or that children will be safer. Research confirms that most drivers pick a speed that they perceive is safe based on their assessment of the driving environment. As a result, simply adding a sign establishing a lower speed limit may have only a marginal effect on actual vehicle speeds.
- Washington County has conducted an investigation of the effects on vehicle speeds associated with designating a school speed zone with flashing lights along a rural road-ways. The results indicate vehicle speeds dropped by five miles per hour and the number of vehicles in the pace dropped by more than 20%.
- The presence of school children during the school arrival and departure is an obvious change in the driving environment and it has been observed that drivers will lower their speeds when children are present. However, if the school is not immediately adjacent to the roadway or if the children do not walk to school, there may be no children visible to drivers. In either case, techniques for improving driver compliance include:
    - Making the signs dynamic with flashers that operate only on days when school is in session and hours when children are likely to be present.
    - Partnering with local law enforcement to occasionally provide a visible presence.
- A final point about school speed limits – the safety of children will be optimized if the establishment of a school speed limit is part of a comprehensive program that also includes consideration of the road geometry (medians and curb extensions have been proven effective at improving pedestrian safety), the use of adult crossing guards, the availability of a sidewalk system (also proven effective at improving pedestrian safety), and strategic fencing of the school property.

Speed Strategies

Highlights

- National research suggests that the most effective speed management strategy, Automated Speed Enforcement, results in both lower speeds and fewer crashes. Crash reductions in the range of 15 to 50% have been documented. Automated Speed Enforcement is currently used in 14 states but not Minnesota, even though public opinion polls show support.
- According to NHTSA, a crash on a road with a speed limit of 65 mph or greater is more than twice as likely to result in a fatality than a crash on a road with a speed limit of 45 or 50 mph and nearly five times as likely as a crash on a road with a speed limit of 40 mph or below.
- Congress repealed the National Maximum Speed Limit on interstate highways in 1995. In 2014, four states have raised posted limits to as high as 80 mph or extended maximum limits to more roads. In all, 38 states have speed limits of 70 mph or higher on some portion of their roads, despite research showing that an increase in traffic deaths was attributable to raised speed limits on all road types (**www.iihs.org/iihs/sr/statusreport/article/49/6/3**).
- Strategies that have been used to address speeding include:
  - Stepped-up high-visibility speed enforcement (HVE) such as Minnesota's Statewide Speed Enforcement Day and speed campaign involving enforcement agencies across the state focusing on speed violations in the summer months, the deadliest time on Minnesota roads. HVE has demonstrated an ability to reduce the number of drivers exceeding the speed limit by more than 10 miles per hour by approximately 30%. However, it was also determined that the effect of this type of saturation enforcement diminished over time (the "Halo Effect"). Observed crash reductions associated with HVE are in the range of 3% to 5% of all crashes during the event.
  - Public information and education programs that publicize upcoming enforcement programs and educate the public on the dangers of speed and aggressive driving.
  - Increase emphasis on employer policies related to driving at legal and safe speeds.

2013 Minnesota Speeding Fact Sheet, Minnesota Department of Public Safety, Office of Traffic Safety, 2014
2014-2019 Minnesota Strategic Highway Safety Plan, Data 2008-2012
Survey of the States: Speeding and Aggressive Driving, 2012, GHSA
Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, 2013, NHTSA

Technology Applications

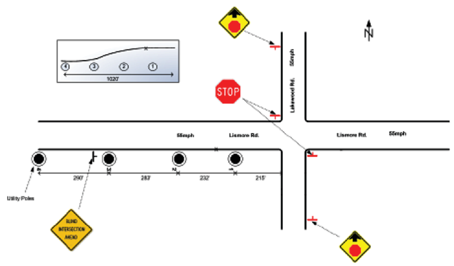


Figure 3: Intersection layout before installation of ALERT-2.

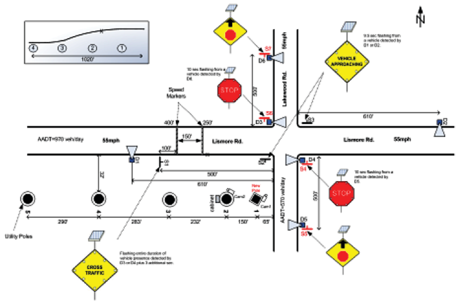


Figure 4: Intersection layout after installation of ALERT-2.

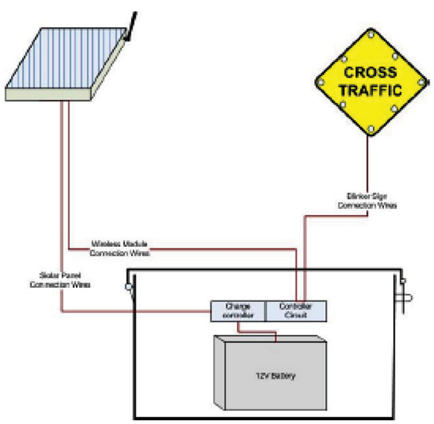


Figure 41: The components of a blinker sign unit.

Highlights

- The FHWA and MnDOT have invested in a considerable amount of research regarding the use of new technology to address traffic operations and safety deficiencies.
- Advanced technologies have been successfully deployed to address freeway traffic management, and a new generation of traffic signal controllers and optical detectors are improving traffic flow on urban arterials.
- Research is currently underway at several universities, including the University of Minnesota, LRRB to better understand factors contributing to intersection crashes in order to develop new devices for assisting drivers in selecting safe gaps at uncontrolled intersections, making safer turns at controlled intersections, and providing additional warning when drivers violate the intersection control.
- In response to an overrepresentation of severe crashes at rural Thru/STOP intersections, MnDOT and the University of Minnesota – Duluth developed and field-tested a new dynamic warning system – the Advanced LED Warning System for Rural Intersections (ALERT)1. The system utilizes four basic technologies:
    - LED signs
    - Renewable energy
    - Non-intrusive sensors
    - Wireless communication
- The system detects the presence of vehicles approaching the intersection on both the major (Thru) and minor (STOP) approaches that activates flashing lights on a series of Warning signs and the STOP sign.
- An evaluation of the system's performance found that vehicle speeds on the major approach were reduced and the number of vehicles that rolled through the STOP sign was eliminated when a conflict existed in the intersection.
- The evaluation did not consider crashes because there were too few crashes at the single intersection selected for the field operational test to be considered statistically reliable.

[1] MnDOT Report No. 2014-10, *Advanced LED Warning System for Rural Intersections: Phase 2 (ALERT-2)*

Impaired Driver Strategies

2013 Minnesota Impaired Driving Fact Sheet, Minnesota Department of Public Safety, Office of Traffic Safety, 2014

2014-2019 Minnesota Strategic Highway Safety Plan, Data 2008-2012

2012 Impaired Driving Crash Facts, Minnesota Department of Public Safety, Office of Traffic Safety, 2013

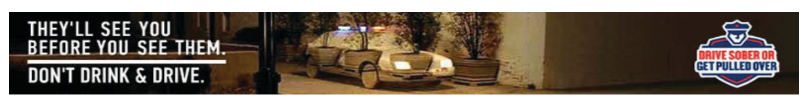
Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, NHTSA, 2013

Ignition Interlocks – What You Need to Know, DOT HS 811 883, NTSA, 2014

NHTSA: **www.trafficsafetymarketing.gov/laborday2014peak**

Highlights

- The legal limit for driving while impaired in Minnesota is 0.08 – but motorists can be arrested for DWI at lower levels. A blood alcohol concentration (BAC) of 0.08 or above is a criminal offense and, in Minnesota, is a violation of civil law that triggers automatic driver license revocation for up to a year.
- Of all offenders in Minnesota, the vast majority – nearly 60% – are first-time offenders; nearly 40% of offenders are repeat offenders with one or more DWIs on record. One out of every seven licensed drivers in Minnesota has at least one DWI.
- Strategies that are proven effective at decreasing impaired driving include:
  - High-visibility impaired-driving enforcement such as the nationwide Drive Sober or Get Pulled Over drunk driving crackdowns combining high visibility law enforcement and public awareness to deter or detect drunk drivers. Research shows that high-visibility enforcement can reduce drunk driving fatalities by as much as 20%.
  - Nighttime belt enforcement. (Note: Each year, nearly 70% of drinking drivers killed in crashes are not buckled up).
  - Alcohol ignition interlocks to separate drinking drivers from their vehicle and reduce repeat DWI offenders.
    - Ignition interlocks have been shown to reduce re-arrest by a range of 50% to 90%.
    - In Minnesota, all repeat DWI offenders – and first-time offenders arrested at twice the legal limit – must use alcohol ignition interlocks or face at least 1 year without a driver's license.
    - In 2012, there were 28,418 impaired-driving incidents in Minnesota and 4,050 interlocks were in use.
    - By comparison, seven states have more than 20,000 interlocks in use, led by Texas (38,000), and three states do not use interlocks (North Dakota, Mississippi and Alabama).
    - Two states have an interlock-in-use to DWI ratio greater than 1.0 –Washington (2.5) and New Mexico (1.1). Minnesota's ratio is 0.2.
  - Administrative license revocation/suspension (immediate license revocation/suspension upon failure or refusal of a BAC test).
  - DWI and drug courts to closely monitor offenders and their treatment.
  - Screening and brief intervention techniques by the courts for DWI offenders.
  - Technical assistance and support to those who prosecute DWI offenses.



Inattention Strategies

ONE TEXT OR CALL COULD
WRECK
IT ALL

Highlights

- Inattention has been found to contribute to approximately 19% of severe crashes and Minnesota law enforcement expects driver inattention or distraction as being significantly underreported.
- Strategies to reduce distracted driving include:
  - **Stepped-up high-visibility enforcement (HVE)** of distracted driving laws, including routine traffic patrols that include distracted driving enforcement to targeted efforts focused on specific events such as the national annual Distracted Driving Awareness Month campaign.
  - **Focusing on high-risk young drivers and using social media** such as Twitter, YouTube, and Facebook, in addition to traditional media, to more effectively communicate the safety risks and changing social norms associated with smart phones, as well as other distractions.
  - **Strengthening public/private partnerships** to reinforce safe driving practices. Minnesota, similar to California, Nebraska, and Texas, is working with its state affiliate of the National Safety Council to provide and develop education and distracted driving policies to major employers – the Minnesota Towards Zero Death Program.
  - **Improving crash data collection** to more accurately determine the magnitude and impact of distracted driving and to support the development of safety solutions.
- Challenges to reducing and enforcing distracted driving include:
  - The motoring public's unwillingness to put down their phones, despite recognizing the dangers of distracted driving.
  - Enforcement officers' ability to discern whether a motorist is texting or dialing a phone, as the latter is permitted in Minnesota and in most states.
  - Distracted driving is under-reported due to driver reluctance to admit being distracted.
  - The lack of funding for enforcement, media, and public education.

Distracted Driving: Survey of the States, 2013, GHSA
2013 Inattentive Driving Facts, Minnesota Office of Traffic Safety
2014-2019 Minnesota Strategic Highway Safety Plan, Data 2008-2012
Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, NHTSA, 2013
Distracted Driving High-Visibility Enforcement Demonstrations in California and Delaware, 2014, DOT HS 811 993
Four High Visibility Enforcement Waves in Connecticut and New York Reduce Hand-Held Phone Use, 2011, DOT HS 811 845.

Unbelted Strategies

Highlights

- Minnesota's seat belt law is a primary offense, meaning drivers and passengers in all seating positions must be buckled up or in the correct child restraint or law enforcement will stop and ticket unbelted drivers or passengers – including those in the back seats.
- Minnesota occupant restraint usage rate is 95% (June, 2013) – the highest in Minnesota history. Nationally, seat belt use is much lower (86% in 2012).
- Properly wearing a seat belt reduces the risk of fatal injury to front-seat passengers by 45% in a car and 60% in a light truck. Seat belts are the most effective means of protecting oneself from injury in the event of a crash.
- In a crash, odds are six times greater for injury if a motorist is not buckled up.
- Minnesotans that are least likely to buckle up and more likely to die in crashes are younger vehicle occupants ages 15 to 29, who annually account for nearly 43% of all unbelted deaths and nearly 50% of all unbelted serious injuries – yet this group represents only 23% of all licensed drivers.
- Strategies that are proven effective at increasing occupant seat belt use include:
  - High-visibility seat belt enforcement (incorporates media and public outreach about the enforcement)
  - Nighttime belt enforcement
  - Focused enforcement and supporting outreach to high-risk, low-belt-use groups.

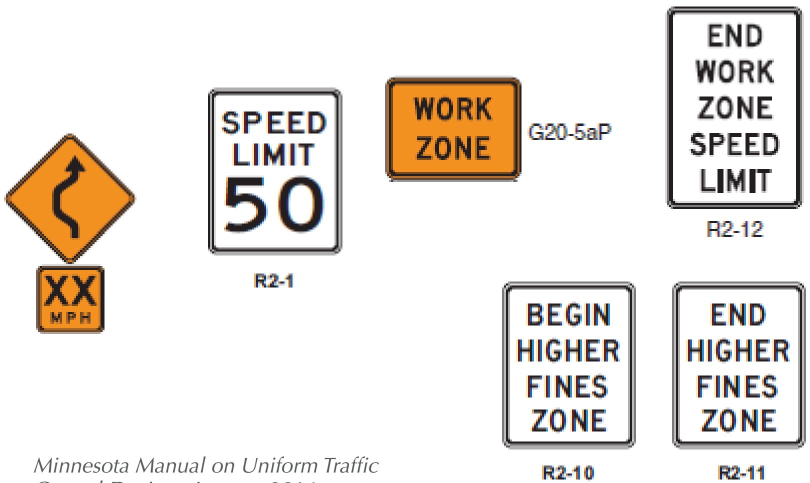
2013 Seat Belt Overview, Minnesota Office of Traffic Safety
2014-2019 Minnesota Strategic Highway Safety Plan, Data 2008-2012
Occupant Protection 2012 Traffic Safety Facts, 2014, NHTSA
Countermeasures That Work: A Highway Safety Countermeasure Guide for State Highway Safety Offices, NHTSA, 2013

Temporary Traffic Control Zones

Highlights

- Addressing crashes in temporary traffic control zones is one of AASHTO's safety focus areas. There were 87,600 crashes in temporary traffic control zones in 2010 that resulted in 576 fatalities and 37,476 injuries.
- Minnesota averages around 1,900 crashes in temporary traffic control zones, with approximately 20 resulting in either a fatality or serious injury.
- Crashes in temporary traffic control zones are identified as a safety focus area in Minnesota's Strategic Highway Safety Plan.
- Temporary traffic control zones can be a challenge for drivers because of a variety of unexpected conditions – distractions, congestion, and a greater demand for more precise navigation.
- A review of Minnesota's temporary traffic control zone crashes found that the most frequent type is a rear-end crash, and common contributing factors include inattention (30%) and speeding (26%).
- Providing an effective speed limit in temporary traffic control zones is extremely important, but it must be noted that signing alone will not reduce vehicle speeds. Drivers must clearly perceive the need to reduce speed based on their reaction to the design of the approach and the placement of traffic control and channelizing devices. Consideration should also be given to having an enforcement presence to further encourage drivers to slow down.

Temporary Traffic Control Zones



Minnesota Manual on Uniform Traffic Control Devices, January 2014

A "When Workers Present" speed limit of 45 mph is required when:

1. At least a portion of entire lane is closed
2. Workers are present

It is not required if,

1. Positive barriers are placed between workers and traveled lanes
2. Work zone is in place for less than 24 hours
3. A 24/7 speed limit is established
4. A reduced speed limit is authorized by the road authority when workers are present

Highlights

- There are three methods of speed limit signing for temporary traffic control zones: Advisory Speeds, 24/7 Construction Speed Limits, and Workers Present Speed Limits.
    - **Advisory Speeds:** Advisory speed plaques combined with Warning signs notify drivers of potentially hazardous conditions, such as bypasses, lane shifts, low and no shoulders, and where visibility may be reduced due to work activities. The use of advisory speed plaques does NOT require authorization from the Commissioner of Transportation
    - **24/7 Construction Speed Limit:** Regulatory speed limits that remain in place on a 24-hour basis and require an order from the Commissioner of Transportation. These speed limits are used where the physical features of the road require lower vehicle speeds, such as bypasses or a two-lane/two-way operation on what is normally a four-lane divided highway.
    - **Workers Present Speed Limit:** Regulatory speed limit, but does NOT require authorization from the Commissioner of Transportation. Minnesota Statute 169.14.5d.(c) allows local road agencies to set a temporary traffic control zone speed limit when workers are present and working directly adjacent to travel lanes.
- Minnesota sets a fine of $300 for violation of a regulatory speed limit in a temporary traffic control zone. As a result, an END WORK ZONE SPEED LIMIT or END ROAD WORK sign must be used to indicate the end of the higher-fine area.
- MnDOT research supports the notion that signing alone will not reduce vehicle speeds. In addition to using the design of the approach to the temporary traffic control zone and the placement of channelizing devices to convey a message to slow down, two other strategies have been shown to achieve speed reductions: the presence of law enforce-ment and the use of dynamic speed feedback signs.

Average Crash Costs

$	10,300,000	Per FATAL Crash
$	550,000	Per SEVERITY A Crash Incapacitating Injury
$	160,000	Per SEVERITY B Crash Non-incapacitating Injury
$	81,000	Per SEVERITY C Crash Possible Injury
$	7,400	Per PROPERTY DAMAGE ONLY Crash

Developed by MnDOT Office of Traffic, Safety and Technology

Highlights

- MnDOT uses the following comprehensive crash costs when computing the expected benefits associated with roadway and traffic control improvements.
- The costs shown were developed in 2013 by MnDOT on a per crash basis for use in calculating benefit/cost comparisons only. The costs include economic cost factors and a measure of the value of lost quality of life that society is willing to pay to prevent deaths and injuries associated with motor vehicle crashes. Costs reflect Minnesota's 3-year crash history and the US DOT procedures contained in *Revised Department Guidance 2013: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses*.
- Due to the very high cost for fatal crashes and the effect this can have on the outcome of benefit/cost analyses, it is the practice in Minnesota to value fatal crashes as 2x"Severity A Crash" ($1,100,000 per crash) unless there is a high frequency of fatal crashes of a type susceptible to correction by the proposed action.

Crash Reduction Benefit/Cost (B/C) Ratio Worksheet

BC
worksheet

Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
	I-494	Portland Ave to Nicollet Ave	3+00.848	4+00.357	Hennepin Co.	1/1/2004	12/31/2006
Description of Proposed Work	Construct Westbound auxiliary lane between Portland and Nicollet						

Accident Diagram Codes		1 Rear End	2 Sideswipe Same Direction	3 Left Turn Main Line	5 Right Angle	4,7 Ran off Road	8, 9 Head On/ Sideswipe -Opposite Direction	Pedestrian	6, 90, 99 Other	Total
Study Period: Number of Crashes — Fatal	F									
Personal Injury (PI)	A									
	B									
	C	3								3
Property Damage	PD	7	3							10
% Change in Crashes (*Recommend using MnDOT's *% Change in Crashes*)	F									
PI	A									
	B									
	C	-25%								
	PD	-25%	-25%							
Change in Crashes (= No. of crashes X % change in crashes)	F									
PI	A									
	B									
	C	-0.75								-0.75
	PD	-1.75	-0.75							-2.50

Year (Safety Improvement Construction)	2013
Project Cost (exclude Right of Way)	$ 600,000
Right of Way Costs (optional)	
Traffic Growth Factor	3%
Capital Recovery	
1. Discount Rate	4.5%
2. Project Service Life (n)	30

Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
F			$ 6,800,000	
A			$ 390,000	
B			$ 121,000	
C	-0.75	-0.25	$ 75,000	$ 7,750
PD	-2.50	-0.83	$ 12,000	$ 3,833
Total				$ 11,583

B/C= 0.47

Using present worth values,

B= $ 283,990

C= $ 600,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Operations November 2007

Note: The Excel™ spreadsheet file may be downloaded from MnDOT's Website

Highlights

- Comparing the expected crash reduction benefits of a particular safety countermeasure to the estimated cost of implementation is an accepted analytical tool used in evaluating alternatives at one location or to aid in the prioritization of projects across a system.
- The basic concept is to give preference to the project(s) that produced the greatest benefit for the least amount of investment.
- The worksheet calculates benefits as the expected reduction in crash costs on an annual basis and compares this value to the annualized value of the estimated construction cost.
- The methodology only accounts for benefits associated with crash reduction. However, the process could be revised to also account for other benefits, such as improved traffic operations (reduced delay and travel times).
- It should be noted that benefit/cost analysis does not attempt to account for all potential benefits associated with any particular project, since some economic and social benefits are very difficult to quantify.
- Substantial research is dedicated to developing crash modification factors (CMFs) to quantify the impact of various safety strategies. Nationwide, CMF studies are stored at the CMF Clearinghouse (www.cmfclearinghouse.org) and should be used to estimate the impacts of various safety strategies when conducting a benefit-cost study.

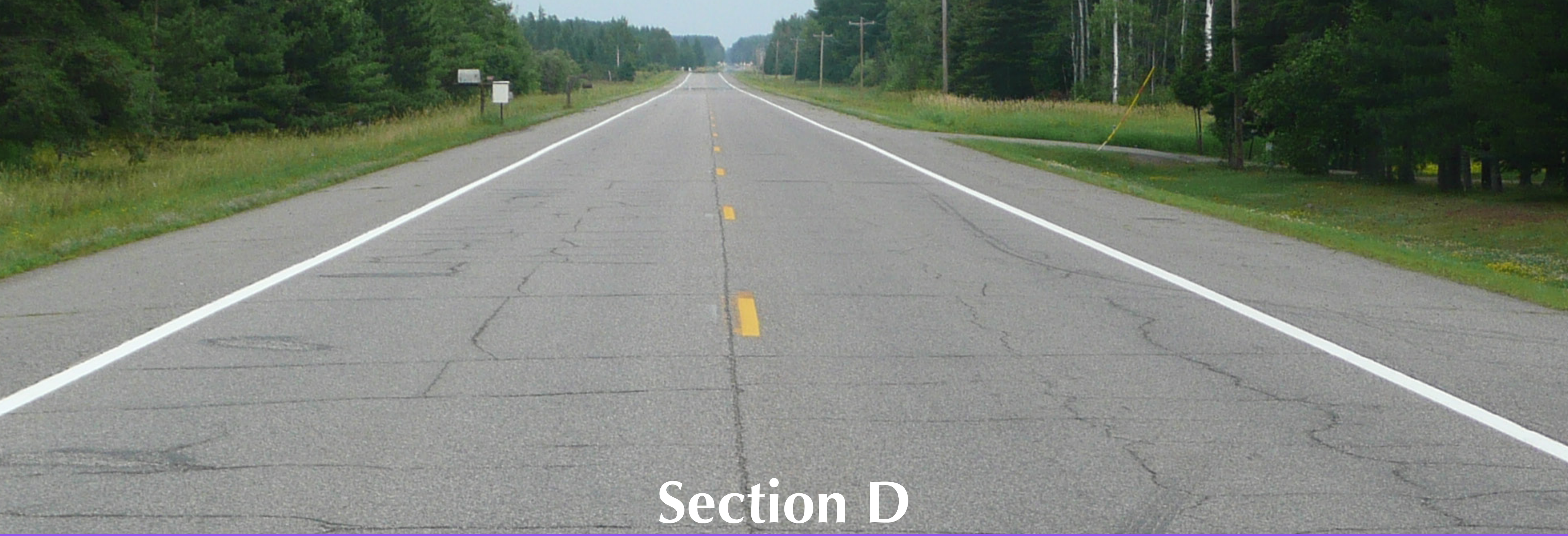
Typical Benefit/Cost Ratios for Various Improvements

Rank	Construction Classification	B/C Ratio
1	Illumination	21.0
2	Relocated Breakaway Utility Poles	17.2
3	Traffic Signs	16.3
4	Upgrade Median Barrier	13.7
5	New Traffic Signals	8.3
6	New Median Barrier	8.3
7	Remove Obstacles	8.3
8	Impact Attenuators	7.8
9	Upgrade Guardrail	7.6
10	Upgraded Traffic Signals	7.4
11	Upgraded Bridge Rail	7.1
12	Sight Distance Improvements	7.0
13	Groove Pavement for Skid Resistance	5.6
14	Replace or Improve Minor Structure	5.2
15	Turning Lanes and Traffic Separation	4.4
16	New Rail Road Crossing Gates	3.9
17	Construct Median for Traffic Separation	3.3
18	New Rail Road Crossing Flashing Lights	3.2
19	New Rail Road Flashing Lights and Gates	3.0
20	Upgrade Rail Road Flashing Lights	2.9
21	Pavement Marking and Delineations	2.6
22	Flatten Side Slopes	2.5
23	New Bridge	2.2
24	Widen or Improve Shoulder	2.1
25	Widen or Modify Bridge	2.0
26	Realign Roadway	2.0
27	Overlay for Skid Treatment	1.9

FHWA, Highway Safety Evaluation System (April 14, 1999)

Highlights

- The FHWA has documented the benefit/cost ratios for a variety of typical safety-related roadway improvements.
- Typical benefits/costs ranged from 1.9 for skid overlays to 21.0 for illumination.
- These benefits/costs should only be used as a guide and not as the definitive expected value at any particular location in Minnesota.
- Benefits/costs in the range of 2 to 21 would likely only be achieved at locations with crash frequencies significantly higher than the expected values.
- MnDOT-funded safety research has documented benefits/costs for a variety of safety projects, including:
  - Street lighting at rural intersections (21:1)
  - Cable median barrier along freeways (10:1)
  - Access management (in the range of 3:1 to 1:1)



Section D

Lessons Learned

Lesson Learned – Crash Characteristics

Highlights

- At the National level the number of traffic-related fatalities during the past 10 years has dropped dramatically from almost 43,000 deaths to just under 33,000.
- Over this same 10-year period, the trend in Minnesota is similar – the number of traffic-related fatalities has declined from over 650 traffic fatalities to fewer than 400 per year.
- In 2013 the national fatality rate was 1.1 fatalities per 100 million vehicle miles traveled and the range was 0.6 to 1.9. Minnesota's fatal crash rate was 0.7 – the second lowest in the country and the lowest of any state not in the northeast.
- Fatal crashes in Minnesota are not distributed evenly across the state – 66% of fatalities are in rural areas and the fatality rate on rural roads is nearly 3 times the rate in urban areas.
- The national safety performance measure is the number of severe injuries – fatalities plus incapacitating injuries.
- Factors that contribute to severe crashes involve drivers, the roadway and vehicles. Driver behavior is a factor in more than 90% of crashes, roadway features are a factor in slightly more than one-third of crashes and vehicle failures are a factor in around 10% of crashes.
- The adoption of the new safety performance measure with a focus on severe crashes has resulted in a better understanding of the fact that fatal crashes are different than less severe crashes. The most common type of crash is a rear-end (31% of all crashes); however, the most common types of fatal crashes include run-off-road (32%), angle crashes (21%) and head-on crashes (20%).
- Crashes are not evenly distributed across the population of drivers – young drivers (under age 21) represent about 6% of all drivers but are involved in almost 11% of crashes.
- Most crashes occur on dry roads in good weather and during daylight conditions – it's a function of exposure. However, nighttime hours present a greater risk for severe crashes – 25% of all crashes occur during dark conditions but 31% of fatal crashes occur during the hours of darkness.
- Contrary to popular opinion, signalized intersections are rarely safety devices. The average crash rate, severity rate, and crash density is higher at signalized intersections compared to the statistics for STOP-controlled locations.
- The most common types of intersection-related crashes are rear-end and right angle. The installation of a traffic signal changes the crash type distribution – increasing rear-end and left turn crashes. However, the fraction of right angle crashes remains virtually unchanged – there is a substantial and widespread problem involving red-light running.
- Crash rates on roadway segments are a function of location (rural vs. urban), design (conventional vs. expressway vs. freeway) and the degree to which access is managed. Rural freeways and two-lane roads have the lowest crash rates, urban minor arterials have the highest crash rates, and rural county highways and township roads have the highest fatal crash rates.
- Urban crashes are predominantly two vehicle (rear-end and right angle) and rural crashes are predominantly single vehicle (run-off-road and deer hits).
- Within design categories of roads (rural two-lane, urban four-lane, expressway, etc.) the density of access can be used to predict crash rates – segments with higher access densities have higher crash rates in both rural and urban areas.
- Severe injury crashes involving pedestrians and bicyclists account for approximately 14% of all severe crashes in Minnesota. Nearly two-thirds of these crashes occur in the Minneapolis-St. Paul Metropolitan Area and the majority of these occur on streets with a 30 MPH speed limit and at intersections controlled by traffic signals.

Lesson Learned – Safety Improvement Process

Highlights

- MnDOT's Strategic Highway Safety Plan (SHSP) is a data-driven document that adopts severe crashes as the safety performance measure (fatal and incapacitating injury crashes). The SHSP also adopts a short-term safety goal – 300 or fewer fatalities by 2020 and the long-term goal of zero fatalities.
- The SHSP identified seven primary safety emphasis areas for Minnesota: traffic safety culture, safety belts, impaired driving, speeding, inattentive, intersections and lane departure.
- In urban areas the primary factors associated with fatal crashes are intersections and the use of safety belts; and in rural areas the primary factors are safety belts, impairment and road departures.
- A comprehensive safety improvement process includes both a site analysis at high crash locations focused on reactive implementation of safety strategies and a systemwide analysis focused on proactively implementing generally low-cost safety strategies broadly across priority locations along an agency's system of roads.
- The recommended analytical method for conducting a detailed study of an individual location involves comparing the actual crash characteristics to the expected characteristics and then evaluating the differences. It is important to note that the expected crash frequency of any given location is never zero.
- Of the three traditional methods for identifying potentially hazardous locations (number of crashes, crash rate, and critical crash rate), the critical crash rate is the most statistically reliable, but this is also the most data-intensive method. However, the use of any method is better than not conducting a periodic safety inventory.
- The recommended method for conducting systemwide safety analyses involves conducting systemic risk assessments. This technique is based on the premise that severe crashes may be widely scattered around a system, but they are not randomly scattered. As a result, a review of locations with severe crashes can reveal a set of common roadway and traffic characteristics, the presence of which at locations with few or no severe crashes can establish a priority for safety investment based on risk.

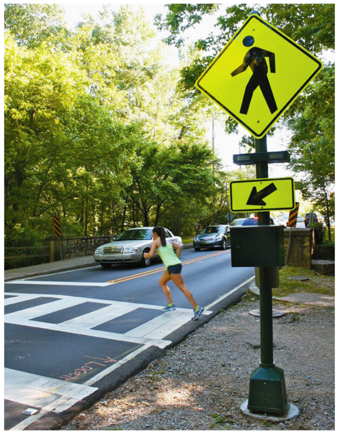
Lesson Learned – Traffic Safety Tool Box

Highlights

- Current traffic safety tool boxes are better stocked and include a more comprehensive set of safety strategies as a result of efforts by NCHRP (Series 500 Reports), FHWA (Crash Modification Factors Clearinghouse) and AASHTO (Highway Safety Manual).
- The selection of safety strategies begins with identification of the types of crashes that are the target of mitigation and also involves consideration of the expected crash reduction.
- Safety program and highway system managers have a bias in project development toward strategies that have demonstrated an effectiveness in reducing crashes. The theory is that if a strategy has been proven successful at reducing crashes at other locations, that strategy will likely result in a similar crash reduction at your location.
- Strategies that have proven to be effective safety mitigations include:
  - Lane departure crashes along rural roads: improved road edge delineation (edge rumble strips and wider edge lines), centerline rumble strips, and enhanced curve delineation (Chevrons).
  - Right angle crashes at rural thru/STOP intersections: improved signs and markings, street lighting, dynamic warning signs, reduced conflict intersections and roundabouts.
  - Rear-end and head-on crashes along urban roads: road diets and access management.
  - Right angle crashes at traffic signals: confirmation lights.
  - Pedestrian crashes: crossing enhancements (countdown timers and advanced walk at traffic signals, curb extensions, median refuge islands and HAWK signals) and sidewalks.
- Speed is a contributing factor in approximately 20% of severe crashes and in response speed reduction is frequently requested. Experience in Minnesota indicates that merely changing the posted speed limit has never been successful at actually lowering operating speeds. Research suggests that enhanced enforcement (sustained as opposed to periodic because the halo effect is as little as a few minutes) and changing the driver's perception of the safe speed (adding urban features such as curb and gutter, boulevard, sidewalks, parked cars, etc.) have proven successful.
- When conducting a safety analysis and especially when dealing with the public on a safety issue, it is considered a best practice to have law enforcement participate in these efforts – they provide a unique perspective and help present a more complete picture of possible strategies – recall driver behavior is a contributing factor in more than 90% of severe crashes.





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