MnDOT District Safety Plan Updates – Project Overview

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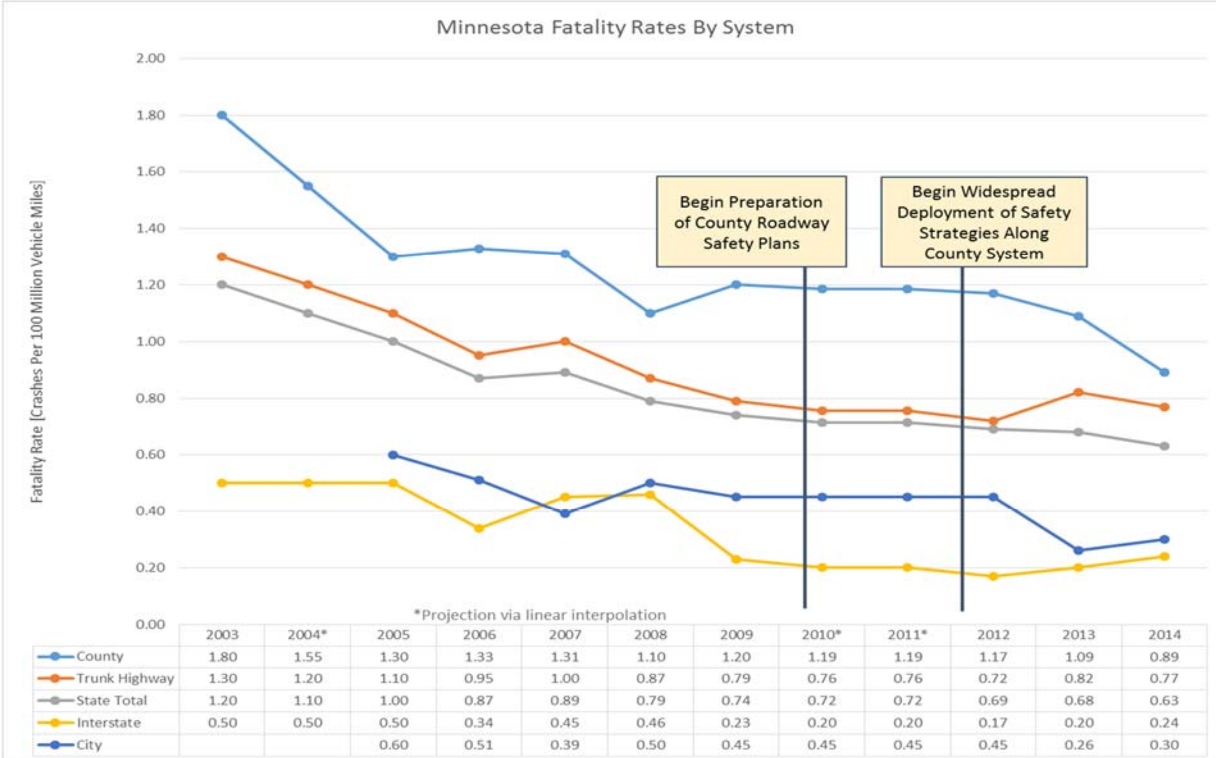
This Technical Memorandum is the final deliverable associated with the preparation of the updated Safety Plans for each of MnDOT's Districts in the Greater Minnesota Region. The document contains six major sections:

- Background
- Methodology
- Overview – Network, Crashes, Strategies
- Analytical Approach
- Statewide Results
- Contribution to HSIP Development

Background

The Minnesota Department of Transportation updated the Safety Plans for the Districts in the Greater Minnesota Region that were originally prepared between 2009 and 2012. The Office of Traffic, Safety and Technology (OTST) provided leadership and strategic oversight for the second comprehensive safety review and analysis across the state's system of Trunk Highways in support of the State's short term crash reduction goal (< 300 traffic deaths by 2020) and in response to two key points:

- The trend line documenting the fatality rate on the state's system (Figure 1) has been flat for several years.
- A systemic risk assessment of Minnesota's system of county roadways was completed in 2013, which generated a number of technical refinements in safety project development. The refinements resulted in a prioritized listing of candidate locations for safety investment and the identification of more than $250M of suggested low-cost safety projects (the average project cost was less than $20K). Since the counties began widespread implementation of these projects, the fatality rate along the county system has dropped by approximately 25 percent.



	2003	2004*	2005	2006	2007	2008	2009	2010*	2011*	2012	2013	2014
County	1.80	1.55	1.30	1.33	1.31	1.10	1.20	1.19	1.19	1.17	1.09	0.89
Trunk Highway	1.30	1.20	1.10	0.95	1.00	0.87	0.79	0.76	0.76	0.72	0.82	0.77
State Total	1.20	1.10	1.00	0.87	0.89	0.79	0.74	0.72	0.72	0.69	0.68	0.63
Interstate	0.50	0.50	0.50	0.34	0.45	0.46	0.23	0.20	0.20	0.17	0.20	0.24
City			0.60	0.51	0.39	0.50	0.45	0.45	0.45	0.45	0.26	0.30

Figure 1. Minnesota Fatality Rates by System

The updated and comprehensive analysis of the Trunk Highway system incorporated the lessons learned from the preparation of the County Roadway Safety Plans and the analytical effort involved a four-level prioritization exercise that identified:

- The focus crash types that are the kinds of crashes with the highest number of occurrences that represent the greatest opportunity for reduction. In addition, the roadway and traffic characteristics common to the locations with the focus crash types were documented and these were used in the systemic risk assessment.
- The prioritization of highway segments, curves and intersections based on a designation of either sustained high crash or high risk. Sustained high crash locations were identified as having a crash rate statistically significantly higher than for similar facilities PLUS the presence of a severe crash and high risk locations were observed to have multiple of the adopted risk factors present. The sustained high crash and high risk locations were considered high priority candidates for safety investment.
- A prioritized list of safety strategies that were considered to be proven effective at reducing the focus crash types.
- Suggested safety projects for a specific safety strategy at the specific locations identified as being high priority candidates for safety investment.

The results of this analytical process provided each district with a comprehensive list of suggested safety projects based on the site analysis approach of identified sustained high crash locations and the systemic risk assessment of the Trunk Highway system based on the set of adopted risk factors.

An integral part of the overall process to identify safety projects involved coordination with district staff. District traffic engineers provided feedback on the definition of sustained high crash locations and the roadway and traffic characteristics used in the systemic risk assessment. In addition, district staff participated in two safety focused workshops. The first workshop focused on brain storming potential innovative solutions for problem locations identified by the districts. The second focused on providing comments on the systemic process and the initial identification of at-risk locations considered priority candidates for safety investment. Finally, district staff reviewed the initial lists of suggested safety projects and decided which projects would make their final comprehensive lists.

Methodology

The methodology used in the analysis for each district in the Greater Minnesota region focused on identifying and prioritizing specific locations along the state's system of Trunk Highways that could be considered candidates for safety investment through MnDOT's Highway Safety Improvement Program (HSIP). Consistent with current guidelines and national best practices, the analysis was comprehensive and identified candidate locations through a site analysis approach at sustained high crash locations and a systemic risk assessment of the entire system of Trunk Highways in each district. In addition, for a designated subset of locations determined to be high priority, safety projects were developed for the implementation of a specific strategy or combination of strategies at a specific location.

A key underlying factor in the analytical process was a recognition that the final list of suggested safety projects identified through the site analysis and risk assessment approaches needed to be balanced. A sufficient number of projects are required to provide each district with flexibility to effectively manage their construction program and to improve safety at as many high priority locations as possible while demonstrating a responsiveness to the concerns of local elected officials and recognizing that HSIP funds are limited. The total level of funding for HSIP is approximately $31 million annually with slightly more than 60 percent reserved for supporting safety projects on local systems, which results in approximately $12.4 million available to support safety improvements on the state's system. The overall level of safety funding (which accounts for slightly more than 1 percent of the state's annual construction program) combined with statewide distribution of funding in proportion to the fraction of fatal and serious injury crashes results in an annual target HSIP allocation for each district ranging from approximately $700,000 to $3.9 million (Table 1).

Table 1. 2017 Allocation of Highway Safety Improvement Program Funds

District	Allocation
1	$1.2 million
2	$660,000
3	$1.9 million
4	$930,000
6	$1.4 million
7	$1.4 million
8	$1.0 million
Metro	$3.9 million
Total	$12.4 million

The crash analysis found that almost 90 percent of severe crashes occurred at locations NOT considered sustained high crash locations. This fact combined with limited funding dedicated to safety supports HSIP manager's bias toward directing safety funds to standalone projects that involve the implementation of highly effective and low-cost strategies that can be widely deployed across the state's highway system.

The phrase highly effective, as it relates to the safety program, is defined as having a proven history of reducing particular types of crashes. A proven history of success provides HSIP managers and district staff with a high level of confidence that deployment of a particular strategy will result in crash reductions because that is what has been documented in the safety research across a large number of prior deployments. The use of low-cost (or relatively low-cost) strategies allow for the widest possible investment across more miles, curves and intersections. Wide deployment of low-cost strategies have been demonstrated to be the most effective approach for mitigating crashes at locations with very low densities, such as rural highway segments and intersections which average around 0.01 severe crashes per mile or per intersection per year.

The approach to funding safety projects used by MnDOT's Office of Traffic, Safety and Technology is consistent with national priorities established by the Federal Highway Administration (FHWA), which encourage the development of standalone safety projects. In addition, it is suggested that candidate locations for safety investment need to be based on either a designation as sustained high crash or high risk in order to justify the safety investment. The site analysis and risk assessment approaches used in the analysis of the state's system of highways provided this kind of information.

Overview

Network

The highway segments, intersections and curves that were part of the assessment were identified and MnDOT's Tool-Kit provided basic information about roadway and traffic characteristics. Major gaps in the information were addressed, for example, over 800 rural intersections were added and a comprehensive database was delivered to MnDOT. In total, 10,720 miles of Trunk Highway, 6,260 intersections and 5,466 horizontal curves were included in the analysis (Table 2).

Table 2. Statewide Network Overview

	Rural			**Urban**	
District	Miles	Curves	Intersections	Miles	Intersections
1 –Duluth	1,434	1,454	419	104	181
2 - Bemidji	1,689	489	772	81	553
3 – Baxter	1,522	969	716	126	265
4 – Detroit Lakes	1,510	631	599	87	241
6 – Rochester	1,278	1,018	641	136	258
7 – Mankato	1,243	449	634	91	283
8 – Willmar	1,317	456	499	84	199

- 10,700 miles
- 6,260 intersections
- 5,500 curve

These totals include all rural highways and intersections in the Greater Minnesota region and a sample of urban segments and intersections. Each district in Greater Minnesota identified seven cities for analysis and the highway segments and associated intersections in those cities were included in the analysis but no highways or intersections in the Metropolitan District were considered as part of the analysis. The data indicates that more than 90 percent of the highway miles and 65 percent of intersections are considered rural and more than 80 percent of rural highway miles are considered to be conventional two-lane highways.

Crashes

The crash data used in the analysis was obtained from the Minnesota TIS database. Consistent with MnDOT practices, the most recent five years of data that was available at the beginning of the study was used (2009 – 2013) and consistent with Minnesota's adopted safety performance measures, the analysis focused on severe crashes, those involving fatalities and serious injuries. The initial analysis identified the Emphasis Areas for the Trunk Highway system (Table 3). This data indicates that the most common types of severe crashes are either lane departure or intersection related and that approximately 69 percent of the severe crashes on the Trunk Highway system occur in Greater Minnesota.

Table 3. Emphasis Areas

		Metro		Greater Minnesota	
Emphasis Area	**Statewide**	**Severe Crashes**	**Percent**	**Severe Crashes**	**Percent**
Total Severe Crashes	**7,071**	**780**	**100%**	**1,702**	**100%**
Nonmotorists	-	109	14%	98	6%
Pedestrian	*9%*	*91*	*12%*	*75*	*4%*
Bicyclist	*4%*	*18*	*2%*	*23*	*1%*
Vehicle/Train	<1%	0	0%	3	<1%
Heavy Vehicle	10%	90	12%	311	18%
Motorcycle	18%	133	17%	232	14%
Intersection	42%	339	43%	622	37%
Lane Departure	46%	307	39%	902	53%
Run-Off-Road	-	*219*	*28%*	*561*	*33%*
Head-On	-	*88*	*11%*	*341*	*20%*
Work Zone	1%	33	4%	32	2%
Deer/Animal	-	7	1%	41	2%
Winter Weather	-	62	8%	294	17%

Used to identify *urban* safety projects. (Nonmotorists)

Used to identify *urban & rural* safety projects. (Intersection)

Used to identify *rural* safety projects. (Lane Departure)

The second, more detailed analysis disaggregated the crash data for Greater Minnesota by rural (Figure 2) versus urban (Figure 3) areas and by highway facility type. This data indicates:

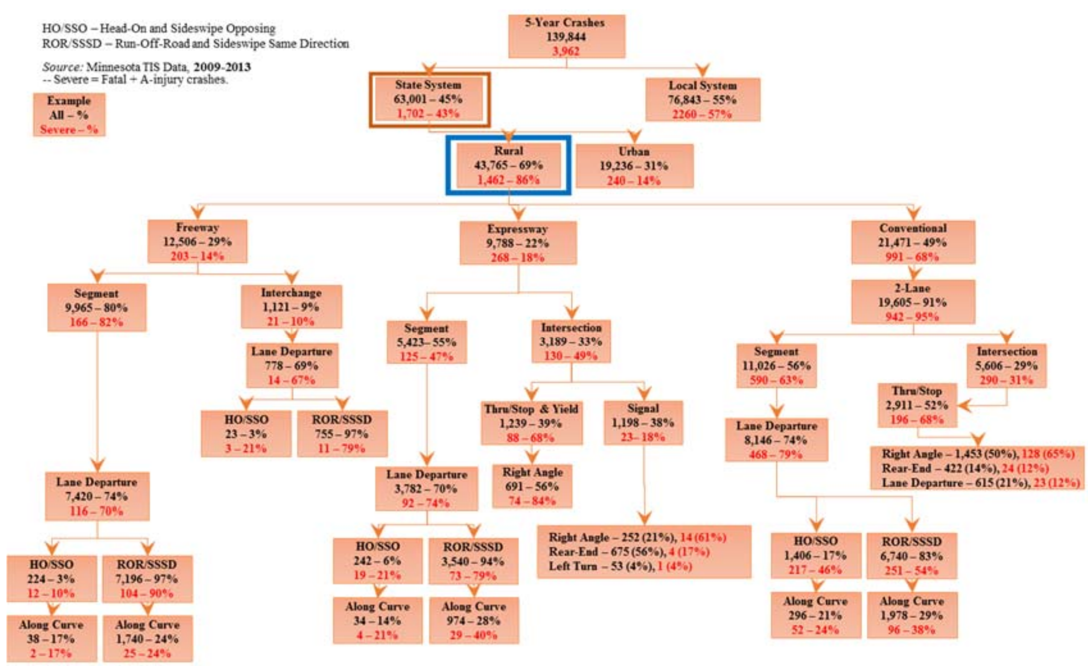


Figure 2. Greater Minnesota – Rural Crash Tree

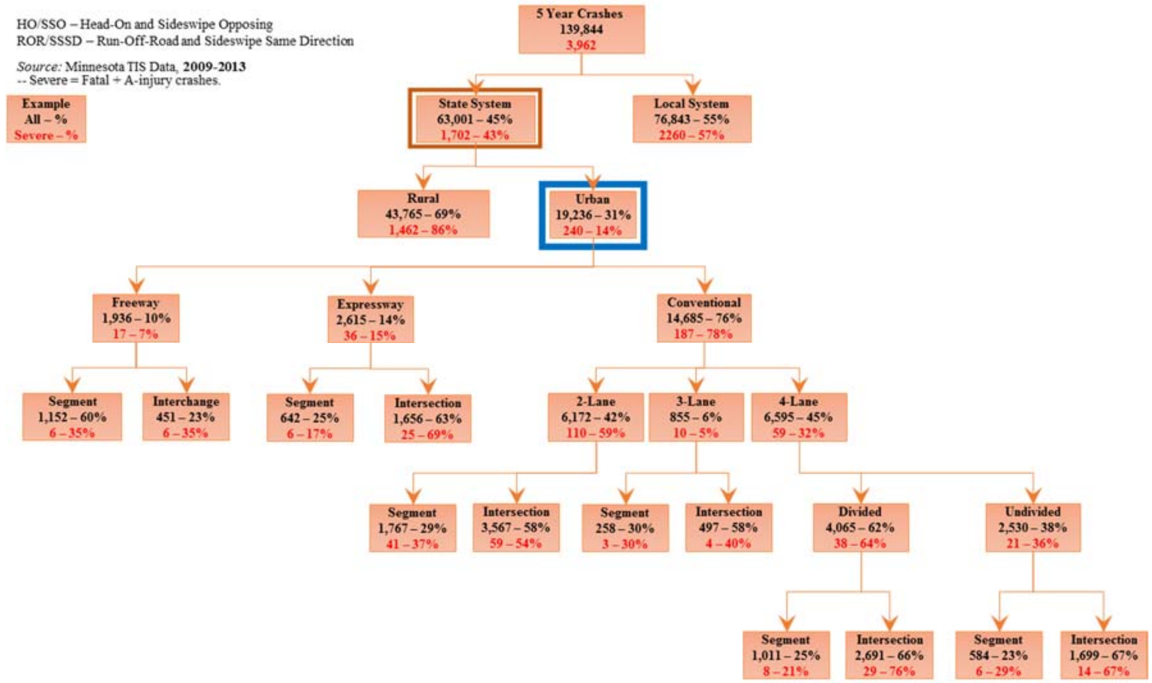


Figure 3. Greater Minnesota – Urban Crash Tree

Rural

- 43 percent of severe crashes were on the state's system.
- 86 percent of severe crashes were on rural highways.
- Of the severe crashes on rural roads, 68 percent were on conventional (primarily two-lane) highways followed by 18 percent on expressways and 14 percent on freeways.
- On rural two-lane highways, 63 percent of severe crashes were segment related versus 31 percent at intersections.
- On rural expressways, there were more intersection related severe crashes (49 percent) compared to segment related severe crashes (47 percent).
- On all rural segments, the most common type of severe crash was lane-departure (81 percent) of which 35 percent are head-on and approximately 30 percent are curve related.
- At rural intersections, 68 percent of severe crashes occur at Thru/STOP control of which the most common type involves a right angle collision (71 percent).

Urban

- In urban areas, 78 percent of severe crashes occur on conventional highways as opposed to 22 percent on highways with some level of access management.
- In urban areas, 59 percent of severe crashes occurred at intersections and these were approximately evenly divided between intersections with traffic signal control and Thru/STOP control (48 percent each).
- The most common types of severe crashes at these urban intersections were right-angle collisions (45 percent) and pedestrian or bicyclist involved (13 percent).

This crash data indicates that a focus on lane-departure crashes along segments and curves and right-angle collisions at intersections with Thru/STOP control in rural areas and right-angle collisions and pedestrian involved crashes in urban areas are priorities for safety investment and represent the greatest opportunity for reducing severe crashes across the state's system of highways.

The data also support a conclusion that crashes involving deer (2 percent) and winter weather (13 percent) should not be considered priorities for safety investments because of the relatively few number of severe crashes. This conclusion is consistent with the priorities documented in Minnesota's Strategic Highway Safety Plan.

Safety Strategies

There are three key points regarding the identification and screening of safety strategies. First, there is no universal safety strategy and the national research tends to group categories of strategies with particular types of crashes. Second, safety program managers have exhibited a bias toward selecting projects that use strategies proven effective at reducing specific types of crashes. The bias is based on an expectation that if the limited amount of safety funds in Minnesota are used to implement strategies proven to reduce crashes at hundreds of other locations around the country, the investment in Minnesota will result in a similar outcome; a crash reduction. Finally, safety program managers also have a bias toward directing the limited amount of safety funds towards projects that involve low-cost strategies. This is in recognition of the extremely low density of severe crashes across the state's highway system and the fact that only around 10 percent of severe crashes occur at locations considered to be sustained high crash.

The basic approach to identifying a short list of high priority safety strategies began with the documentation of the focus crash types and a review of the national research that supported the development of a comprehensive list of potential strategies the conduct of a series of screening exercises. The review of national research (National Cooperative Highway Research Program Report 500 Series and FHWA's Crash Modification Factor Clearinghouse) and MnDOT's Strategic Highway Safety Plan indicates that there are more than 600 potential safety related strategies. This universe of strategies included more than 30 to mitigate lane-departure crashes, more than 70 strategies intended to improve intersections with Thru/STOP control and more than 40 strategies for intersections with traffic signal control.

The initial screening eliminated strategies determined not to be feasible based on consideration of factors such as climate (raised pavement markers) or agency practices (installing reflective material on fixed objects such as trees or utility poles). Subsequent rounds of screening were based on documentation of crash reduction factors (CRF'S), the quality of the research on which the CRF's are based, implementation costs (lower costs are preferred) and consistency with priorities established in Minnesota's SHSP.

The initial lists of safety strategies and the screening factors (CRF's and typical installation costs) were shared with the districts for review and comment. The adopted lists of high-priority safety strategies for rural and urban facilities are documented in Tables 4 through 8. These lists of high-priority strategies were then used in the subsequent development of safety projects across all districts.

Table 4. Strategies – Rural Segments

Strategy	Crash Reduction Factor	Typical Installation Costs
Centerline Rumble Strip	40% head-on/sideswipe crashes 14% all crashes 15% all injury crashes 21% all head-on and opposite direction sideswipe crashes 25% head-on and opposite direction sideswipe injury crashes	$3,600 per mile
Buffers Between Opposing Lanes	50% for all crashes & 100% for head-on crashes [based on TH 5 in Lake Elmo, MN]	$150,000 to $500,000 per mile
Shoulder / Edge Line Rumble Strip	20% run off road crashes 16% all crashes 17% all injury crashes 10% all single-vehicle run-off-the –road crashes 22% single-vehicle run-off-the-road injury crashes	$5,850 per mile
Safety Edge	5% to 10% 5.7% all crashes	
Enhanced Edge Line (Embedded wet-reflective, 6" or 8" edge lines)	10% to 45% all rural serious crashes (6")	$1,980 per mile

Table 5. Strategies – Rural Intersections

Strategy	Crash Reduction Factor	Typical Installation Costs
Upgrade Signs and Pavement Markings	40% upgrade of all signs and pavement markings/ 15% for STOP AHEAD pavement marking 31% all crashes	$2,640 per approach
Streetlights (and approaches)	25% to 40% of nighttime crashes 38% nighttime injury crashes 42% nighttime pedestrian injury crashes	$6,000 per light
All-Way Stop/Yield	48% all crashes	$1,000 per intersection
Rural Intersection Conflict Warning System (RICWS)	50% all crashes/75% severe right angle crashes	$50,000 per intersection
Offset T-Intersection		
Roundabout	20% to 50% all crashes/ 60% to 90% right-angle crashes; 48% all crash/78% injury crashes 71% all crashes/87% injury crashes	$1M - $5M ~$2.5M per intersection
Turn Lanes (Offset, Channelized)	27% injury crashes	
Reduced Conflict Intersection (including RCUT, ¾ intersection, median closing)	17% all crashes/ 100% angle crashes 51% all crashes	$750,000 per intersection

Table 6. Strategies – Rural Curves

Strategy	Crash Reduction Factor	Typical Installation Costs
Chevrons*	20% to 30%	$3,960 per curve
Delineators*	18% to 34% 45% all crashes	
High Friction Surface Treatment (HFST)	24% total crashes 17% rear end crashes 30% single-vehicle crashes	
Dynamic Curve Signing*		$50,000 per curve
Lighting	28% all night time crashes	
Clear Zone Maintenance/Enhancements	[See Rural Segments]	
Reconstruct → TT to Single T Intersection		
Widen Shoulder + shoulder / edge line rumble strips		
Enhanced/Embedded Edge Line		
* Address MUTCD sign requirements based on speed differentials		

Table 7. Strategies – Urban Intersections

Strategy	Crash Reduction Factor	Typical Installation Costs
Echelon		
Continuous Flow Intersection (CFI)		
Signalized RCUT		
Confirmation Lights	25% to 84% reduction in violations	$1,200 per two approaches
Traffic Enforcement Cameras (D3 Example)	17% fatal crashes/26% right-angle and left-turn crashes 17% fatal and injury crashes	
Pedestrian Countdown Times	25% vehicle/pedestrian crashes 70% pedestrian crashes	$12,000 per intersection
Leading Pedestrian Intervals	Up to 60% pedestrian/ vehicle crashes 37% to 44.6% bicycle and pedestrian crashes	$600 per intersection
Curb Extensions	Increase in vehicles yielding to pedestrians	$36,000 per corner
Center Island Medians	46% in vehicle/pedestrian crashes	$24,000 per approach

Table 8. Strategies – Urban Segments

Strategy	Crash Reduction Factor	Typical Installation Costs
Road Diet [3- & 5-Lane Conversions]	30% to 50% 29% all crashes	$48,000 per mile [three-lane] $54,000 per mile [five-lane]+$36,000 per signalized intersection for updates (for example, loop and signal head placement)
¾-Intersection	25%	$150,000 per location
Divided Roadway	22% (HSM §13.4.2.6)	$5M to $10M per mile
Access Mgmt (Access Mgmt Plan)	5% to 31% 31% to 25% all injury crashes	$360,000 per mile
Bike Lane/Boulevard	Approximately 60% (Some studies have noted increases)	
Urban Design Features (make it feel urban)		
Dynamic Speed Feedback Sign	46% all crashes	$30,000 per location
Confirmation Lights (applied to a corridor)		
Pedestrian Amenities (Curb Extensions and Medians applied in a corridor)	[See Urban Intersections]	
Signal Installation along with Reduce Conflicts at Adjacent Intersections		
Signal Coordination	25% to 38% all crashes – NCHRP 500: Vol 12	

Analytical Approach

The safety analysis of the state's system of highways in Greater Minnesota was comprehensive, separate studies were completed in order to identify locations determined to be sustained high crash based solely on the number of crashes and to identify locations determined to be high risk based on a combination of roadway characteristics, traffic characteristics and crashes.

Sustained High Crash

The initial analysis focused on identifying intersections that met the definition for sustained high crash locations – a Fatal + "A" Injury Crash Rate above the Critical Rate OR the Total Crash Rate above the Critical Rate and at intersections, at least ONE severe crash during a 5-year study period or for segments, 0.2 severe crashes per the five year study period. The Critical Crash Rate is a statistical technique that compares the actual crash rate at an intersection to the expected value in order to identify the approximately 5 percent of intersections where the actual rate is statistically significantly higher than expected.

This effort identified 212 intersections along the state's system of highway in Greater Minnesota as sustained high crash locations. These intersections were considered to be candidates for safety investment and were included in the safety project development exercise.

In addition to identifying the sustained high crash intersections (approximately 3 percent of all intersections), the analytical effort produced another key conclusion. The 530 severe crashes at these sustained high crash intersections accounted for approximately 10 percent of all severe crashes across the state's system o' highways. This suggests that a companion effort, conducting a systemic risk assessment of the state's system, is required to provide a more comprehensive list of candidate locations for safety investment.

High Risk – Systemic Risk Assessment

The crash analysis supports the notion that identifying candidates for safety investment through the documentation of sustained high crash intersections is a necessary part of a comprehensive safety program, but not sufficient. The combination of high severe crash rates and at least one severe crash identified approximately 3 percent of the intersections along the state's system as sustained high-crash locations. However, the severe crashes at these intersections accounted for around 10 percent of all severe crashes, which means that approximately 90 percent of severe crashes occur at locations with no crash history or a history that is not statistically different from what is expected. The detailed crash analysis indicates that the remaining severe crashes are widely distributed across more than 6,000 intersections and more than 10,000 miles of state highways, resulting in an average density of 2 severe crashes per intersection or per mile every 100 years.

MnDOT faced a similar challenge with the initial efforts to engage Minnesota's counties in the state's HSIP. The extensive county system had a large number of crashes but few sustained high crash locations, which resulted in very low densities. It was concluded that a traditional approach relying on the documentation of sustained high crash locations would not be effective at identifying candidate locations for safety investment. From a safety perspective, the entire county system was considered potentially at-risk due to the lack of sustained high crash locations and the basic uniformity – the roadways and intersections looked very much alike. However, the small amount of available safety funds required that the county facilities be prioritized, the safety program is simply not large enough to invest across the entire system. To address this issue of prioritization, MnDOT developed a new analytical technique, the systemic risk assessment that was applied to the entire county system to identify and prioritize the fraction of locations determined to be at-risk for severe crashes based on the presence of a combination of roadway and traffic characteristics.

The basic premise behind the systemic approach is that severe crashes may be widely scattered around the highway system, but they are NOT random. The data from previous studies indicates that severe crashes share similar characteristics and an examination of the system can identify the risk factors that support the prioritization of candidates for safety investment. The segments, intersections and curves with more of the characteristics associated with the locations with severe crashes are considered to be more at-risk and, therefore, a higher priority for safety investment. This analytical technique proved successful in the application to the county system; a set of risk factors were adopted and locations with multiple risk factors were identified as high-priority candidates for safety investment. Ultimately, more than 36,000 miles, 20,000 curves and 15,000 intersections were analyzed and this effort resulted in the development of more than 17,000 safety projects (a specific mitigation measure at a specific location) valued at more than $245 million (an average of slightly more than $14,000 per project).

The approach used to identify risk factors in this update of the district's safety plans was similar to that used in the systemic risk assessment of the county system. Crash data for the state's highway system was reviewed along with information for the locations with severe crashes obtained from video logs, aerial photography and a variety of MnDOT data bases. The results of this effort combined with information from national research (NCHRP Report 500 Series and FHWA's CMF Clearinghouse) along with Minnesota's Strategic Highway Safety Plan resulted in an initial set of risk factors that were submitted to the district traffic engineers for review and comment. The final list of roadway and traffic characteristics used in the risk assessment of rural highway segments, curves and intersections are documented in Table 9 and the risk factors for urban facilities in Table 10. The final set of roadway and traffic characteristics used in the assessment of the state's system is similar to those used to evaluate the county roadway system, with four notable exceptions:

- The range of traffic volumes on two-lane rural highways associated with locations with severe crashes is higher on the state's system. On the state's system, the majority of severe crashes occurred on segments with traffic volumes greater than 2,000 vehicles per day. On the county system, the majority of severe crashes occurred on segments with volumes under 1,000 vehicles per day. The adopted traffic related risk factor on the state's system was a volume greater than 3,500 vehicles per day versus the range 600 to 1,200 vehicles per day on the county system.

- The upper end of the at-risk range of curve radii on two-lane rural highways is higher on the state's system. The adopted curve related risk factor on the state's system were radii between 500 feet and 1,800 feet (which accounted for 46 percent of severe lane-departure crashes) versus 500 feet to 1,200 feet on the county system (63 percent of severe lane-departure crashes).
- The traffic related risk factor at both rural and urban intersections along the state's system was expressed as a cross product while an ADT ratio (Major approach volume/Minor approach volume) was used for the county system.
- The risk factors for rural divided highways were entirely new since there are no divided highways on the county system.

Table 9. Rural Segment, Curve, and Intersection Risk Factors

	2-Lane Undivided		4-Lane Expressway		4-Lane Freeway	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Rural Segments						
Shoulder Width	-	2 ft				
Critical Radius Curve Density	0.1	Unlimited	0.25	Unlimited	0.125	Unlimited
Median Width			-	65 ft		
Edge Risk Assessment	2	3				
Access Density	8	Unlimited	5	Unlimited		
ADT Range	3500	Unlimited	16,000	Unlimited	20,000	Unlimited
Severe Lane Departure Density	0.014	Unlimited	0.037	Unlimited	0.028	Unlimited
Interchange Density					0.4	Unlimited
Rural Curves						
Radius	500	1800	500	3750		
ADT Range	2000	Unlimited	16,000	Unlimited		
Severe Lane Departure Density	0.007	Unlimited	0.019	Unlimited		
Visual Trap	Present		Present			
Intersection on Curve	Present		Present			
Shoulder Width	-	4 ft				
Rural Intersections						
Skew	10˚	Unlimited	10˚	Unlimited		
On/Near Curve	Present		Present			
Adjacent Development	Present		Present			
Previous Stop >5 Miles	Present		Present			
Volume Cross Product	400,000	Unlimited	6,000,000	Unlimited		
Severe Right Angle Density	0.007	Unlimited	0.022	Unlimited		

Table 10. Urban Segment and Intersection Risk Factors

	Minimum	Maximum
Urban Segments		
ADT	9000	Unlimited
Road Geometry	Multi-Lane (4+)	
Access Density	36	Unlimited
Speed Limit	35	45
Primary Land Use	Urban or Suburban Retail	
Severe HO + RE + SSP + SSO Crash History	0.019	
Urban Intersections - Right Angle		
Cross Product	3000000	Unlimited
Traffic Control	Signal	
Major Corridor Speed	40	Unlimited
Skew	5	Unlimited
Adjacent Curve	Present	
Primary Land Use	Urban or Suburban Retail	
Severe Right Angle Crash History	0.006	
Urban Intersections - Ped/Bike		
Cross Product	3000000	Unlimited
Traffic Control	Signal	
Major Corridor Speed	35	Unlimited
Skew	5	Unlimited
Adjacent Curve	Present	
Primary Land Use	Urban or Suburban Retail	
Severe Ped/Bike Crash History	0.001	

The selection of the risk factors required analysis of crash data and the characteristics of the locations with the focus crash types in order to identify the roadway and traffic features that were common along the segments and at the curves and intersections where severe crashes occurred. The objective of this effort was to identify characteristics present at a minority of locations where a majority of the crashes occurred. This type of analytical process supported the prioritization of the state's system. Four examples of the type of data that was reviewed and the results that supported the selection of the particular risk factor and provided an indication of prioritization include:

- Rural Two-Lane Intersections – Previous STOP > 5 miles (Figure 4): 57 percent of severe Right Angle crashes occurred at the 44 percent of intersections where the STOP sign on the minor approach was more than 5 miles from the previous STOP sign.
- Rural Two-Lane Curves – Curve Radius (Figure 5): 46 percent of severe lane-departure crashes occurred on the 30 percent of curves with radii between 500 and 1,800 feet.
- Rural Two-Lane Intersections – Proof of Concept (Figure 6): 55 percent of all severe crashes and 65 percent of severe Right Angle crashes occurred at the 27 percent of intersections that had three of more of the risk factors present.
- Rural two-Lane Intersections – Proof of Concept (Figure 7): The average density (crashes/intersection/year) of severe crashes and severe Right Angle crashes increased with the increasing number of risk factors present. The average crash density at the group of intersections designated to be at-risk (three or more risk factors) is six times the average density at not at-risk intersections (fewer than three risk factors).

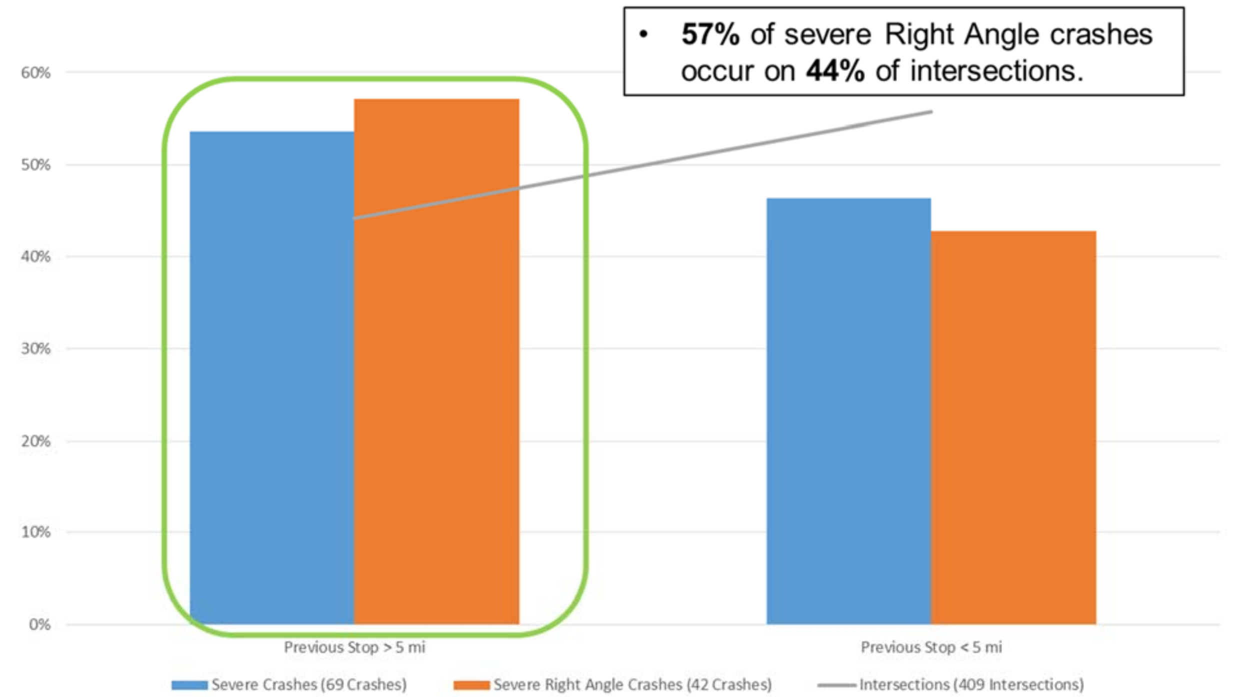


Figure 4. Rural Two-Lane Intersections – Previous STOP > 5 miles

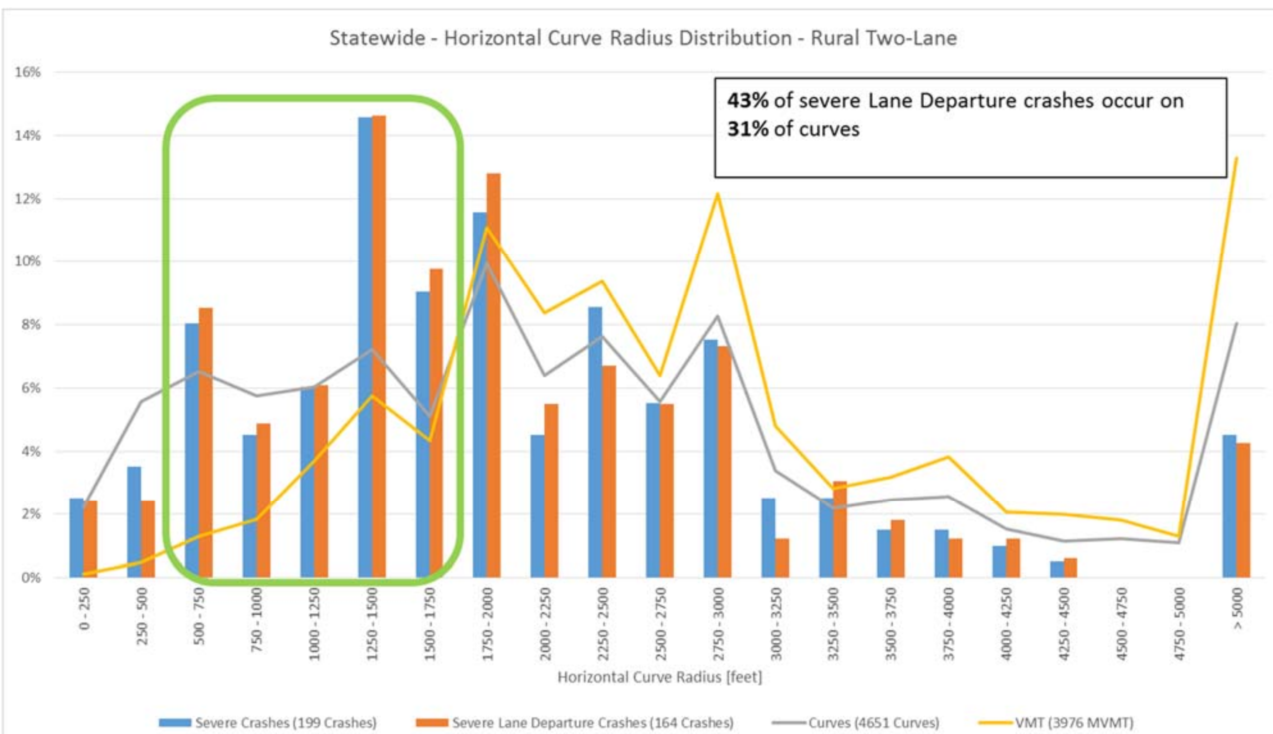


Figure 5. Rural Two-Lane Curves – Curve Radius

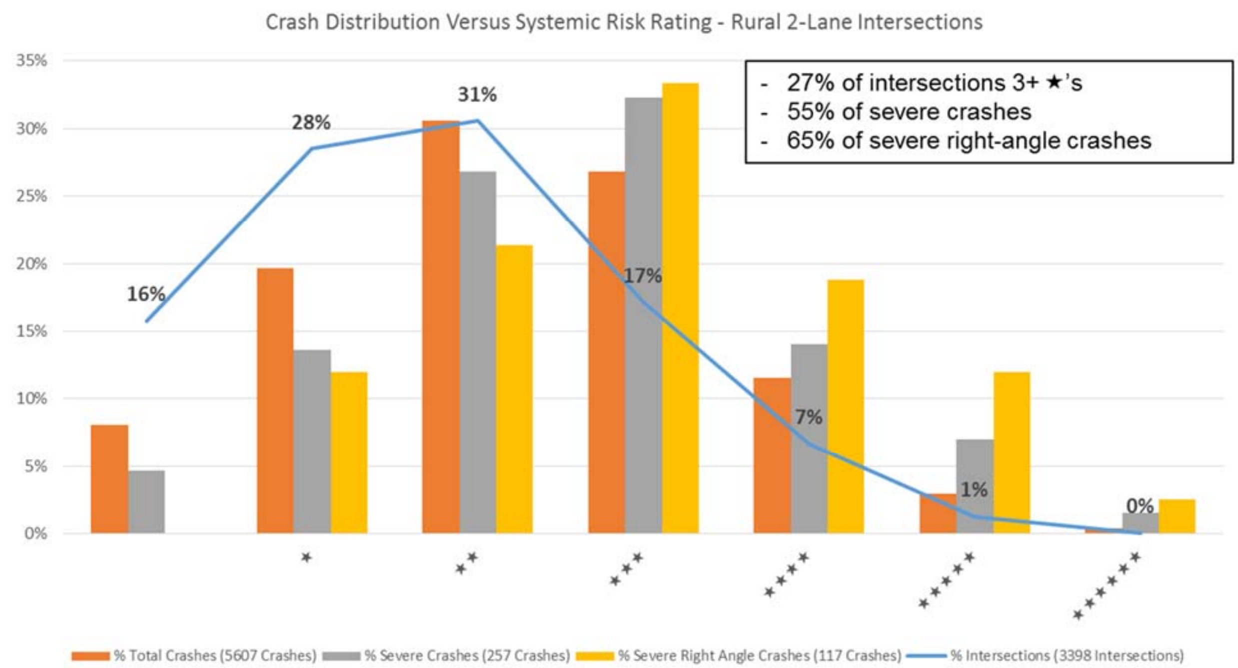


Figure 6. Rural Two-Lane Intersections – Proof of Concept – Percent of Crashes by Risk Factors

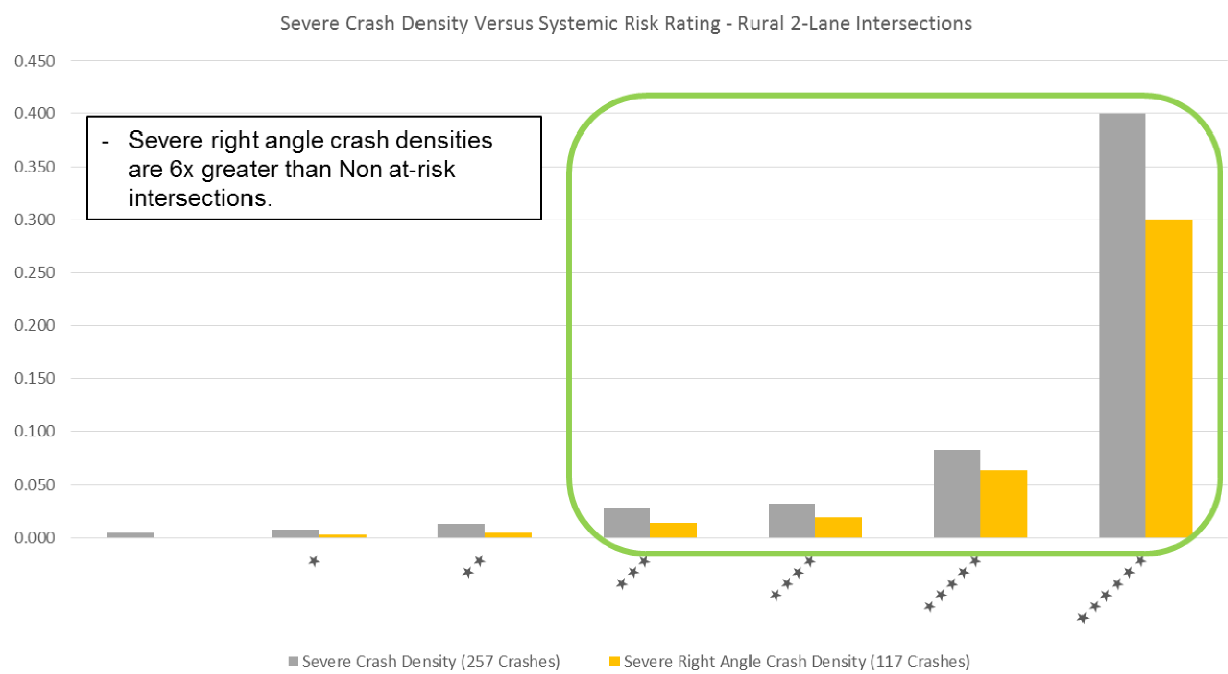


Figure 7. Rural Two-Lane Intersections – Proof of Concept – Crash Densities by Risk Factors

This data also supports the notion that severe crashes are not uniformly distributed across the state's system and the presence of these roadway and traffic characteristics are associated with greater risk. In all cases, as the number of risk factors increased the number of locations declined and the density of severe crashes increased. These trends also clearly support the concept of prioritization, only a fraction of the state's system had multiple risk factors present at any given location and the greater the number of factors present the higher the density of crashes.

The approach to conducting the systemic risk assessment of the state's system involved conducting an evaluation of segments, curves and intersections using aerial photography, video logs and various electronic data bases, identifying the locations where the adopted roadway and traffic characteristics are present and then preparing prioritized lists of these facilities based on the number of risk factors present. The locations with multiple risk factors were considered high priority candidates for safety investment.

Safety Project Development

The basic objective of the safety planning effort was the preparation of individual safety plans for each district that included a prioritized listing of rural and urban facilities and a comprehensive list of safety projects; deployment of specific strategies at specific high-priority locations identified through the sustained high crash and high risk analyses. The effort to define safety projects included a focus on consistency among the districts. A high level of importance was placed on developing similar projects for similar locations with similar characteristics (as identified through the risk assessment) across the entire state highway system. It was considered highly desirable from a human factors perspective to help shape drivers expectations by providing a common set of roadway characteristics at similar locations, no matter where drivers happen to be in Minnesota. To achieve this level of consistency in safety project development, the initial efforts to define projects were guided by decision trees. The decision trees outlined a thought process and provided guidance for safety analysts in the consideration of roadway and traffic characteristics that helps point to a preferred strategy from among a menu of possibilities. Samples of decision trees for rural two-lane segments (Figure 8) and rural two-lane intersections (Figure 9) illustrate how characteristics such as traffic volume thresholds, crash history, and the presence of specific risk factors lead to the identification of a preferred strategy.

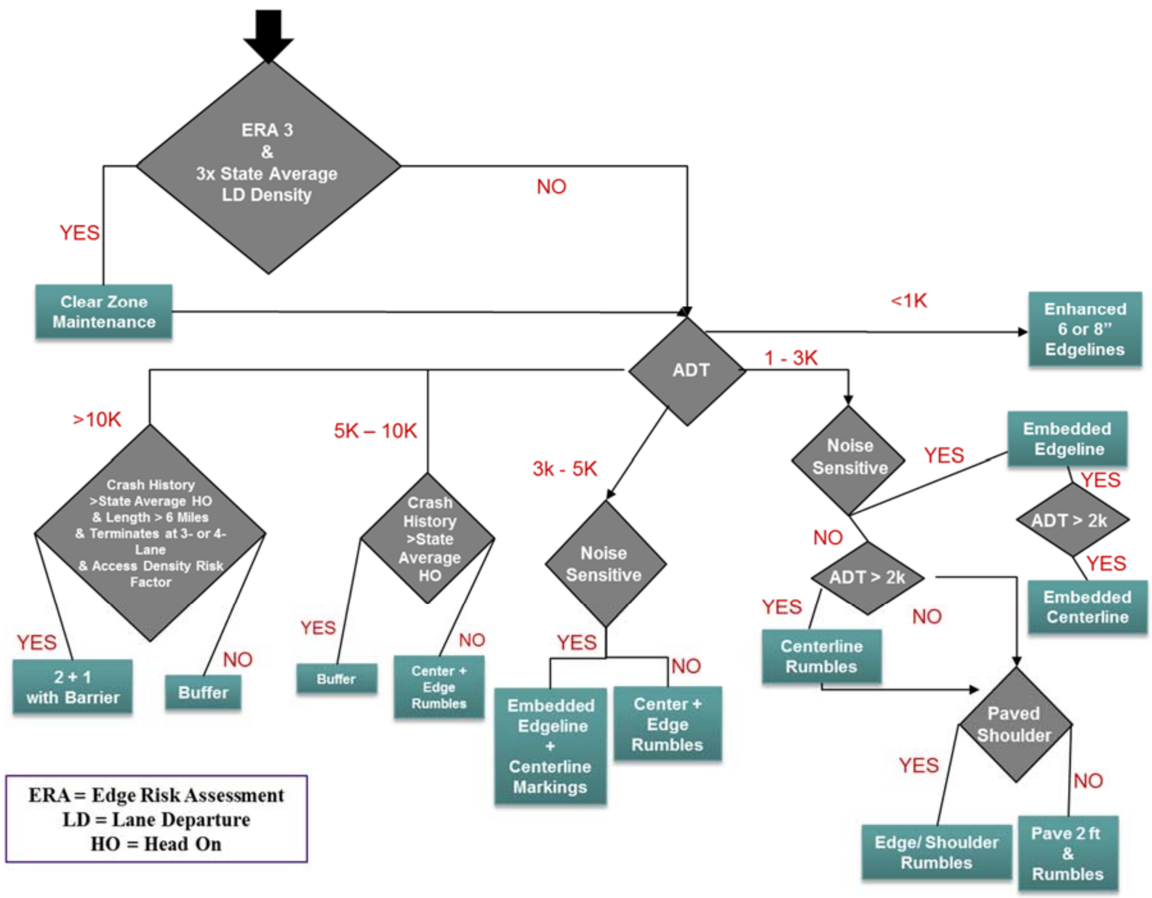


Figure 8. Decision Tree – Rural Two-Lane Segments

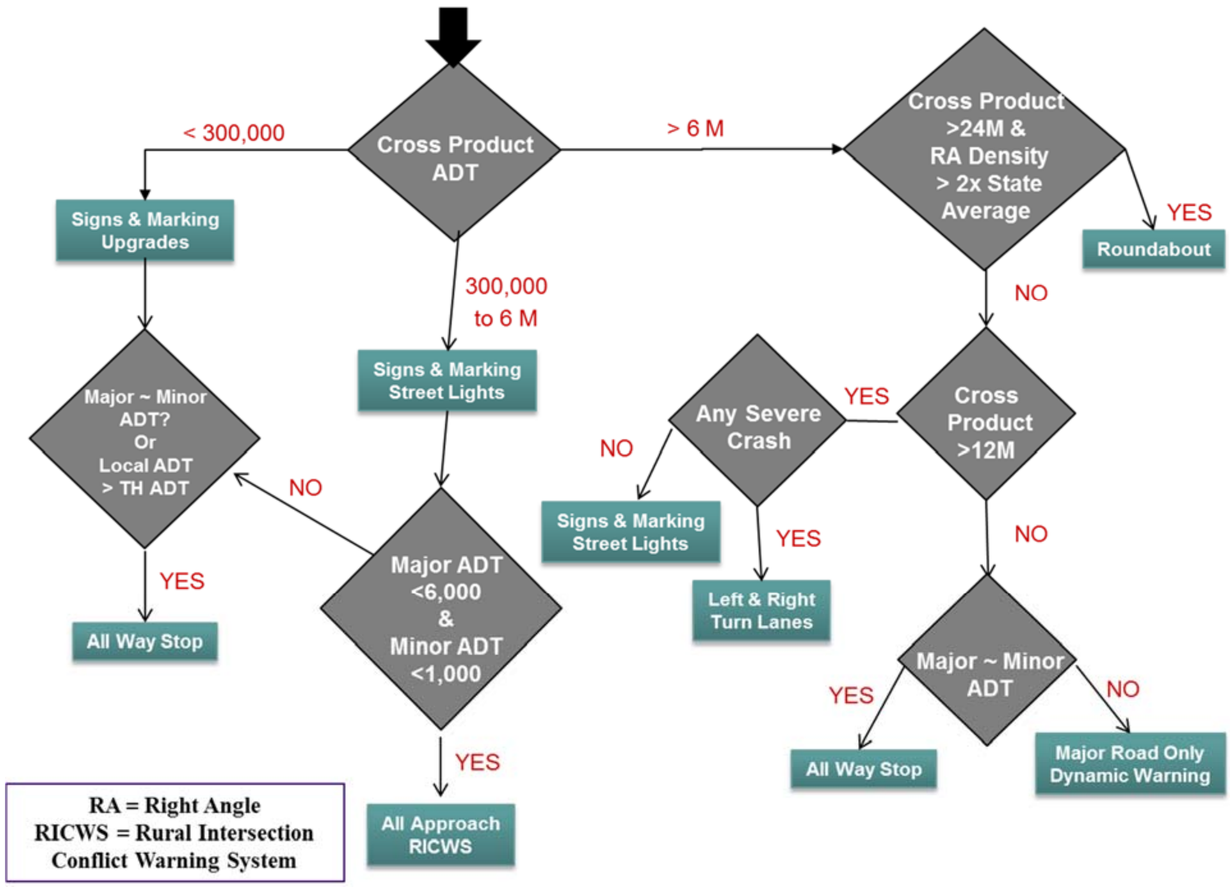


Figure 9. Decision Tree – Rural Two-Lane Intersections

Decision trees were used to produce an initial list of suggested safety projects that were then reviewed by district staff. These reviews resulted in four outcomes:

- Approval of the suggested projects.
- Modification to some of the suggested projects (selection of another strategy).
- Designation of some of the suggested projects as low priority based on the determination that they were not consistent with current district priorities.
- Deletion of a number of suggested projects determined to be outside the district's acceptance due to concerns about effectiveness and increased maintenance costs.

The actual outcome varied across the districts – ranging from two accepting all of the suggested projects (Districts 6 and 8) to two accepting around 50 percent of the projects (Districts 3 and 7).

Statewide Results

Sustained High Crash Intersections

The state's system of more than 6,260 rural and urban intersections were evaluated to identify the subset of locations that met the established definition of a sustained high-crash location – a crash rate statistically significantly higher than the average value for similar intersections and where there was at least one severe crash (fatal or "A" injury) over the five-year study period. This effort identified 212 intersections (about 3 percent) that met the definition. A district by district breakdown (Table 11) found that District 8 had the greatest number of high-crash intersections (47) and District 7 had the fewest (9).

Table 11. District Breakdown of Sustained High Crash Intersection

District	SHCL Intersections	Severe Intersection Crashes	Severe Crashes At SHCL	% of Severe SHCL Crashes	ALL Severe Crashes	% of All Severe Crashes
1	27	65	36	55%	368	10%
2	38	63	47	75%	243	19%
3	41	116	51	44%	602	8%
4	13	66	15	23%	296	5%
6	37	88	46	52%	454	10%
7	9	57	9	16%	300	3%
8	47	75	55	73%	302	18%
Total	212	530	259	49%	2,565	10%

Noteworthy characteristics associated with the sustained high crash intersections include:

- Slightly more than three-quarters of these intersections are considered rural.
- A total of 259 severe crashes occurred at the 212 high-crash intersections during the five-year study period. This results in an average crash density of 0.2 severe crashes per intersection per year, which is about ten times the average for all 6,260 intersections.
- Of the 212 high-crash intersections, only 39 (18 percent of sustained high crash intersections and 0.6 percent of all intersections) had more than one severe crash during the five-year study period. Only one intersection along the state's system (Trunk Highway 52 at Goodhue County Highway 9) averaged more than one severe crash per year. This intersection (which represents 0.5 percent of sustained high crash intersections and 0.02 percent of all intersections) had six severe crashes during the five-year study period and was recently upgraded to a grade-separated interchange.
- 17 percent of high-crash intersections had traffic signal control compared to 9 percent of all intersections having signal control.
- The average density of severe crashes at high-crash intersections varied by the type of intersection control – the density at intersections with traffic signal control was 0.04 severe crashes per intersection per year versus 0.01 at intersections with Thru/STOP control.
- The most common type of severe crash at the sustained high crash intersections was a Right-Angle collision. The average density of these severe Right-Angle collisions was 0.02 at locations with traffic signal control and 0.007 at locations with Thru/STOP control.
- Approximately 49 percent of all severe intersection crashes occurred at the high-crash intersections.
- The number of severe crashes at the high-crash intersections represents 10 percent of all severe crashes – 90 percent of severe crashes along the state's system occurred at locations that are not considered to have a history of severe crashes.

Following a review of the high-crash intersections in each district, a total of 296 safety projects were identified at 179 of the 212 intersections using the adopted lists of safety strategies and the decision trees (more than one project was suggested at many of the high-crash intersections). At the 33 high-crash intersections where no project was suggested, district staff concluded that they had either already implemented a project, had already identified an improvement project or had decided that no improvement was necessary. The 331 suggested projects primarily consisted of:

- Upgraded signs and markings and street lights at rural two-lane intersections.
- Reduced conflict intersections (RCI's) at expressway intersections.
- The addition of confirmation lights and countdown timers at urban signal controlled intersections.

The 296 projects had an estimated implementation cost of approximately $12 million (an average project cost of approximately $40,000), the number of projects ranged from 29 in District 6 to 55 in Districts 7 and 8 and the high-crash project costs ranged from $200,000 in District 4 to $3.4 million in District 3 (Table 12).

Table 12. District Breakdown of Sustained High Crash Intersection Projects/Costs

District	Number of Projects	Estimated Costs
1	40	$1,634,600
2	40	$1,194,000
3	44	$3,343,400
4	33	$207,000
6	29	$2,178,000
7	55	$1,798,400
8	55	$1,562,000
Total	296	$11,917,400

Sustained high crash Locations

The analytical process used in the update of the District Safety Plans included a systemic risk assessment to provide a comprehensive approach to identifying candidate locations along the state's system of highways for safety investment. The results of the analysis of high-crash locations, which found that approximately 10 percent of severe crashes occur at high-crash intersections reinforces the value of this complementary approach by conducting a thorough evaluation of the rest of the system where more than 90 percent of severe crashes occur. The systemic risk assessment process was applied to 10,299 miles of state highways, 5,107 intersections and 5,462 horizontal curves. The assessment process consisted of searching the state's system of highways for the presence of roadway and traffic characteristics that were determined to be common at the locations with severe crashes. The presence of multiple characteristics at the same location was used to identify those considered to be at-risk and therefore, high-priority candidates for safety improvement.

The systemic risk assessment found 3,274 miles, 1,334 intersections and 1,584 horizontal curves to be at-risk, approximately 25 percent of the state's highway system (Table 13).

Table 13. District Breakdown of Sustained High Crash Locations

District	Number Qualified for Projects	Number of Severe Crashes at Qualified Locations	Number All Ranked	Number of Severe Crashes at Ranked Locations	% of System Qualified	% of Severe Crashes at Qualified Locations
Intersections						
1 – Duluth	240	41	526	61	46%	67%
2 – Bemidji	115	26	979	62	12%	42%
3 – Brainerd	328	66	897	104	37%	63%
4 – Detroit Lakes	126	30	656	66	19%	45%
6 – Rochester	237	60	742	83	32%	72%
7 – Mankato	128	22	638	50	20%	44%
8 – Willmar	160	39	669	70	24%	56%
Total	1334	284*	5107	496	26%	57%
Segments						
1 – Duluth	120	148	297	238	40%	62%
2 – Bemidji	64	62	254	141	25%	44%
3 – Brainerd	157	266	412	408	38%	65%
4 – Detroit Lakes	65	71	230	185	28%	38%
6 – Rochester	122	197	349	285	35%	69%
7 – Mankato	45	50	185	198	24%	25%
8 – Willmar	56	53	322	204	17%	26%
Total	629	847	2049	1659	31%	51%
Rural Curves						
1 – Duluth	317	26	1454	53	22%	49%
2 – Bemidji	158	18	489	23	32%	78%
3 – Brainerd	346	52	965	71	36%	73%
4 – Detroit Lakes	227	18	631	28	36%	64%
6 – Rochester	243	44	1018	73	24%	60%
7 – Mankato	150	15	449	28	33%	54%
8 – Willmar	143	15	456	22	31%	68%
Total	1584	188	5462	298	29%	63%

* At-Risk intersection had 10% more severe crashes than the high crash locations

Noteworthy characteristics associated with the identified high-risk locations include:

- The locations identified as high-risk based on the presence of roadway and traffic characteristics had crash densities higher than the system wide average.
- The small number of the most at-risk locations had crash densities substantially higher than the system average, which were also higher than the average crash density at the high-crash intersections.
- There were 847 unique severe crashes at the identified high-risk locations, of which 284 occurred at intersections and 188 in horizontal curves, compared to the 259 severe crashes at the high-crash locations.
- The number of severe crashes at the high-risk locations points to the primary advantage of adding the systemic safety approach to supplement the traditional use of the sustained high crash analysis. The outcome of the systemic analysis presents the opportunity to proactively implement safety improvements at locations that collectively have more than three times as many severe crashes as the sustained high crash intersections, but where many of the individual high-risk locations have yet to experience a severe crash. This provides a very powerful answer to a question frequently asked of MnDOT staff following a severe crash – how many people have to die before something is done to address a perceived dangerous situation? In many cases the answer can be – No One.

Safety Projects were identified at the high-risk locations using the decision trees and the results were reviewed by district staff. The end result was the identification of 3,023 systemic based safety projects with an estimated implementation cost of slightly more than $350 million (Table 14). The average cost of these projects was slightly less than $100,000.

Table 14. District Breakdown of High Risk Projects/Costs

District	Number of Projects	Estimated Costs
1	677	$60,634,300
2	337	$23,382,724
3	831	$113,803,132
4	418	$15,298,909
6	602	$93,306,138
7	323	$10,267,573
8	359	$37,441,710
Total	3,547	$354,134,486

Approximately three-quarters of these projects were on rural systems with the most common types of projects consisting of enhanced pavement markings and center and edge rumble strips on two-lane highways, cable barriers along expressways, enhanced curve warning signs, upgraded signs/marking/street lights at two-lane intersections plus RCI's at expressway intersections. In urban areas, the most types of projects included improved access management, confirmation lights at signalized intersections and pedestrian amenities (Table 15).

Table 15. Systemic Based Project Overview

At-risk Locations	Number of Projects
Rural	
2-Lane Segments	$71,543,613
Expressway Segments	$22,495,788
Freeway Segments	$9,686,250
Curves	$22,667,776
2-Lane Intersections	$50,289,000
Expressway Intersections	$49,748,000
Urban	
Urban Segments	$37,078,859
Urban Intersections (Right Angle)	$79,167,400
Urban Intersections (Ped/Bike)	$11,457,800
Total	$354,134,486

A secondary objective of the analysis associated with the update of each district's safety plan was to provide data to support the an independent MnDOT project that is currently underway – the evaluation of rural two-lane highways for the purpose of consideration of increasing the posted speed limit from 55 to 60 miles per hour. The systemic risk assessment included documentation of the current posted speed limit in addition to noting the presence of the adopted risk factors. The results of this analysis (Figure 10) reveal two key points:

- MnDOT's previous evaluations of rural two-lane highways for the purpose of increasing the speed limit to 60 miles per hour appears to have prevented changing the speed limit on the most at-risk highway segments – no segments with five or six risk factors present had their speed limit changed.
- On segments with one, two, three or four risk factors present, changing the speed limit to 60 miles per hour had an adverse effect on safety. The severe crash density on these segments with a 60 mph limit was approximately 50 percent higher than on similar segments with a 55 mph limit.

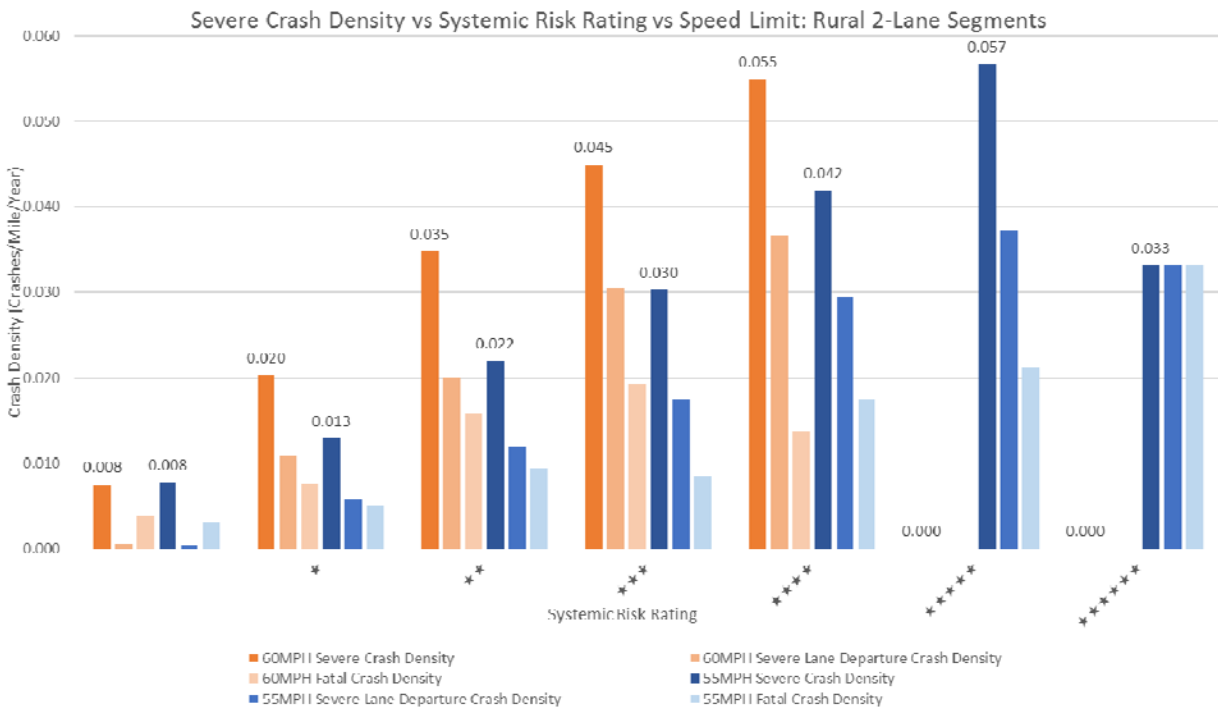


Figure 10. Systemic Risk Assessment Results – 55 MPH versus 60 MPH

There are two final points about statewide results that are noteworthy. The high-crash and high-risk analyses used 2009 – 2013 crash data based on what was available at the time the analyses were begun. However, at the end of the project two additional years of data became available. Based on schedule and budget issues, it was decided that the analyses could not be redone but it was also decided to look at the new data and see how well the systemic approach and the adopted risk factors would have done relative to prioritizing the system. The data was reviewed for rural two-lane segments (Figure 11) and rural two-lane intersections (Figure 12). The results indicate that on the rural two-lane segments, 41 percent of severe crashes occurred in the 29 percent of segments considered to be high risk and at rural two-lane intersections 47 percent of severe crashes occurred at the 26 percent of intersections considered to be high-risk. The conclusion of this effort is that the systemic risk process was effective at prioritizing these facilities.

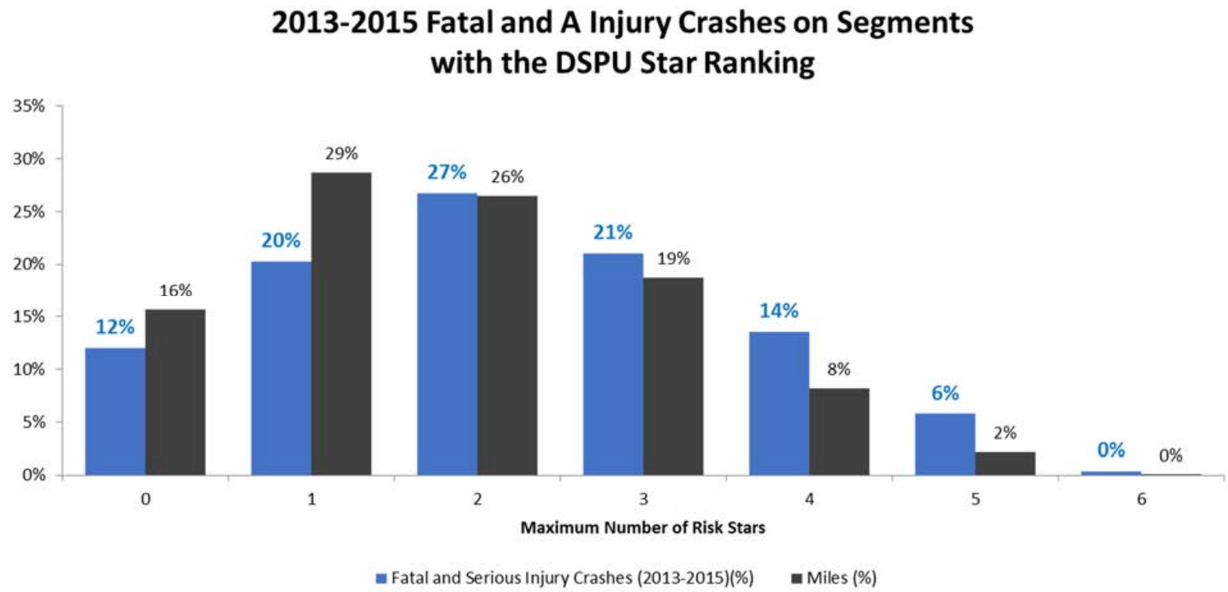


Figure 11. Look Back – Systemic Risk Output Rural Two-Lane Segments

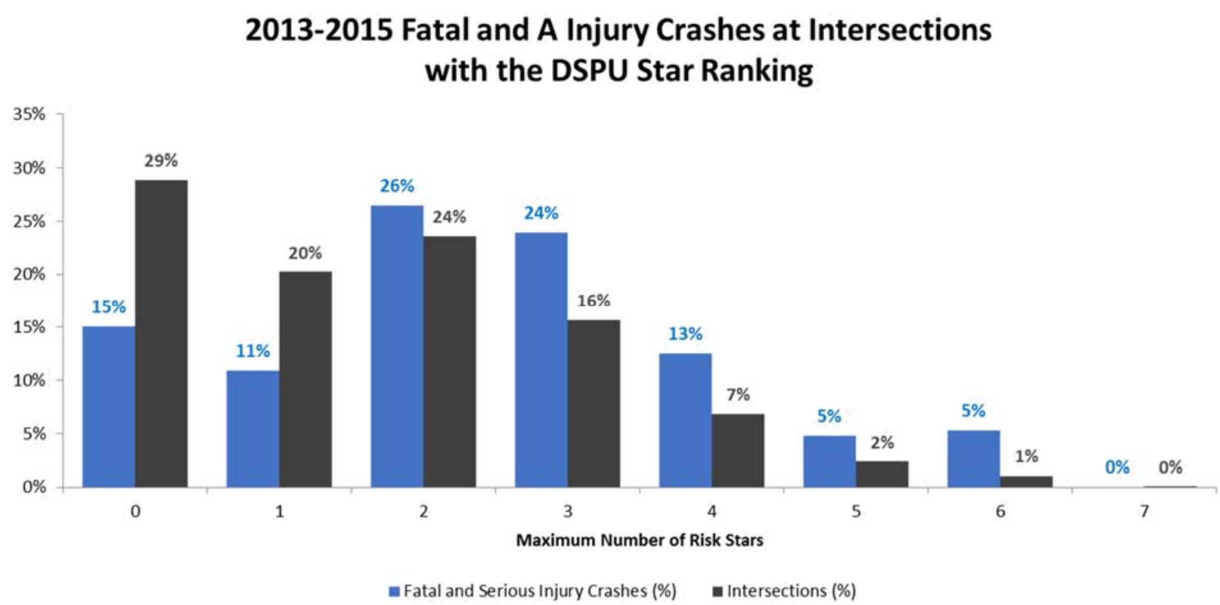


Figure 12. Look Back – Systemic Risk Output Rural Two-Lane Intersections

Potential Collaborations with Driver Behavior

National data indicates that between 60 and 90 percent of crashes were a result, at least in part, of driver behavior. Minnesota's data is similar and indicates that most serious crashes could be prevented if drivers could be persuaded to: buckle up, drive at safe speeds, pay attention and plan ahead for a safe ride after drinking. MnDOT district safety staff should be aware of the fact that even if Minnesota's state highway system is the best-engineered for safety, the crash problem will not be addressed until drivers make safer choices. Leveraging infrastructure strategies together with driver behavior strategies would strengthen the impact of implementation, which would lead to future reductions of severe crashes.

Examples of potential infrastructure based safety strategies that are enhanced through interdisciplinary TZD collaboration include:

- Deploy lane departure strategies coupled with enhanced enforcement. To maximize the safety benefits of lane departure strategies (center and edge line rumbles, and enhanced pavement markings) consider integrating with increased enforcement presence at targeted high-risk locations together with media outreach about enforcement.
- Couple the expanded use of Red Light confirmation lights with enhanced enforcement. It has been determined that the installation of confirmation lights is a necessary part of addressing the most common type of severe crash at signalized intersections (Right Angle collisions), but by themselves are not sufficient – the presence of law enforcement to ticket violators is required. In addition, media outreach and public education about the confirmation lights and enhanced enforcement would help to deter aggressive driving.
- Use changeable message signs to support enforcement campaigns. MnDOT district support of statewide law enforcement saturations through the use of both overhead and portable changeable message signs to display safety-related massages, such as “Extra DWI Enforcement” helps deter high-risk impaired driving by increasing the public’s perceived risk of being stopped.

Contribution to HSIP Development

The primary objectives of the effort to update the district’s safety plans included conducting the first comprehensive analysis of the state’s system of highways, prioritize the system based on both the presence of crashes and an adopted set of risk factors, generate a comprehensive data base that could be used as a resource to assist with future analyses of the state system and finally to identify a set of suggested safety projects (specific strategies at specific high priority candidate locations) that were considered eligible for funding through the State’s Highway Safety Improvement Program. The comprehensive analysis and the prioritization exercise were completed. Evidence of the effectiveness of the prioritization has also been provided – the top ranked locations represent between 25 and 30 percent of the system but account for almost 50 percent of severe crashes. The comprehensive data base was delivered to MnDOT and MnDOT staff have shared a story that they were able to use the data base to complete an assignment dealing with horizontal curves in a matter of hours instead of weeks. Finally a total of more than 3,300 suggested safety projects with an estimated implementation cost of $354 million identified through the systemic assessment and approximately $12 million identified through the sustained high crash assessment bringing the grand total to more than $365 million included in the districts safety plan updates (Table 16).

Table 16. District Breakdown of Safety Project Costs

District	Sustained High Crash	High Risk	Sustained High Crash + High Risk
1	$1,634,600	$60,634,300	$62,268,900
2	$1,194,000	$23,382,724	$24,576,724
3	$3,343,400	$113,803,132	$117,146,532
4	$207,000	$15,298,909	$15,505,909
6	$2,178,000	$93,306,138	$95,484,138
7	$1,798,400	$10,267,573	$12,065,973
8	$1,562,000	$37,441,710	$39,003,710
Total	$11,917,400	$354,134,486	$366,051,886

The final point relates to the apparent acceptance of the validity of the analytical process and the results – or the projects submitted by the districts for inclusion in the Department's 2017 Highway Safety Improvement Program, approximately 80 percent ($12 million of a total $15 million program) came directly from their updated safety plans and workshops.