Fatal Head-On Crashes on Rural Two-Lane Two-Way Highways in Minnesota

A Report Submitted to the

Minnesota Department of Transportation

By

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Minnesota Department of Transportation

January 30, 2015

Executive Summary

This study aims to determine whether passing related maneuvers trigger the high number of fatal crashes on two-lane two-way highways. The public and others perceive that fatal head-on crashes are a result of drivers who attempt to pass others on two-lane two-way highways. Public officials advocate for additional passing lanes and four lane expansions to alleviate these fatal crashes.

The Minnesota Department of Transportation (MnDOT) reviewed 251 fatal head-on crashes on Minnesota two-lane two-way highways. After careful review of police crash reports, seven (7) of 251 fatal crashes involved passing. The remaining 97% of the crashes involved vehicles drifting over the centerline, losing control of the vehicle, weather, and incorrect lane use. Drifting over the centerline alone accounted for 162 (65%) of the fatal crashes.

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Methodology

This study aims to understand the contributing factors of fatal head-on crashes on two-lane two-way highways and the relationship with traffic volume, roadway geometry such as horizontal curvature, weather factors, and other contributing factors.

For these purposes, head-on crashes were limited to those in which one vehicle directly collided with another vehicle driving in the opposite direction. These analyses were limited to fatal crashes. The primary contributing factors were determined using the police narrative, contributing factors 1 and 2, vehicle pre-crash maneuvers, and apparent physical condition of the drivers in the crash report. Special attention was given to determine if a passing maneuver was being attempted.

If the contributing factors, or the crash report itself, was unclear or confusing, the Crash Reconstruction Report was consulted. The Crash Reconstruction Report is created by the Minnesota State Patrol Crash Reconstruction Team. These reports include additional information beyond the original crash report such as exact speeds, data from the vehicle computers, interviews, and other additional insight. This information was collected and added to the data-set. These analyses include crash records for January 1, 2009 through December 31, 2013.

Findings

Head-on crashes account for only 5% of the total number of crashes, yet over 18% of the fatal crashes. Head-on crashes are typically severe, and the second most deadly type of crash; among severe crashes, head-on crashes are surpassed by right angle crashes.

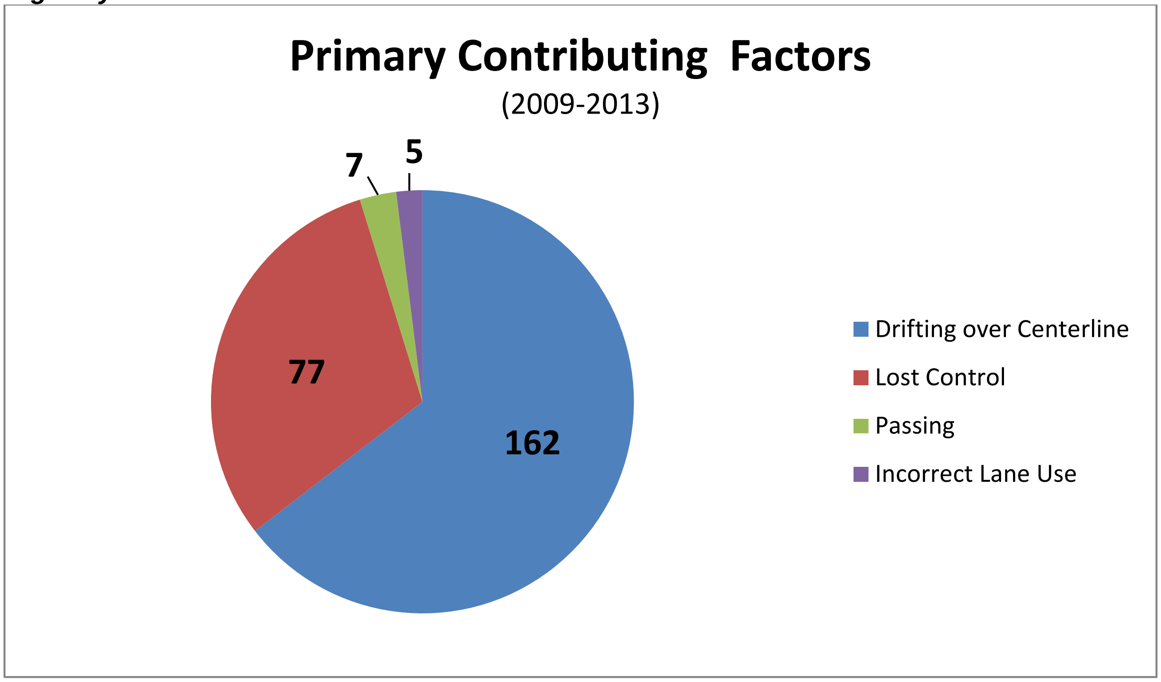
Using information from the crash report, crashes were assigned to one of four primary contributing factors: drifting over the centerline, losing control/weather-related, passing, and incorrect lane use. Other contributing factors or factors of interest included speeding, alcohol use, inattention, sleeping, and the presence of horizontal curves. Two hundred fifty-one crashes fit the selection criteria. Table 1 shows the primary contributing factors for vehicles involved in a head-on crash.

Table 1: Vehicle action prior to a fatal head-on crash (2009-2013)

Description	Number of Crashes	Percent of Crashes
Drifting over centerline	162	64.5%
Loss of Control	77	30.7%
Passing	7	2.8%
Incorrect Lane Use	5	2.0%
Total	**251**	**100%**

Source: Minnesota Crash Mapping Application (MnCMAT), June 2014.

Figure 1: Primary Contributing Factor for Fatal Head-On Crashes on Minnesota two-lane two-way Highways



Source: MnCMAT, June 2014.

Secondary contributing factor were collected based on the crash report and the officer narrative. Not all crashes had a secondary contributing factor. Other factors that were collected are in Table 2.

Table 2: Secondary Contributing Factor for Fatal Head-On Crashes on Minnesota two-lane two-way Highways (2009-2013)

Secondary Contributing Factor	**Number of Fatal Crashes**	**Percent of Crashes**
Alcohol use / Chemical Impairment	28	11.1%
Drifted over centerline due to weather conditions	17	6.7%
Lost control due to weather	55	21.9%
Curve	63	25.1%
Inattention	25	10.0%
Other	19	7.6%
Total	**207**	**82.5%**

Source: MnCMAT, June 2014. Minnesota Department of Public Safety, Driver and Vehicle Services (DVS), June 2014.

The description of “Drifted over centerline due to weather conditions” in Table 2 is a description for when a vehicle drifted over the centerline from poor weather conditions and an inability for the driver to distinguish that they went into the opposing lane. This is as opposed to “Lost Control due to Weather”, when a driver lost control of their vehicle due to weather conditions.

Passing maneuvers do not significantly contribute to head-on crashes. Based on these analyses, factors such as drifting over the centerline and drivers who suddenly lose control of their vehicle are the primary contributing factors to these fatal crashes. Other major factors appear to be the use of alcohol, unknowingly drifting over the centerline due to weather, inattention, and the failure to properly negotiate a horizontal curve.

Roadway System Classification

The State of Minnesota has several different roadway system classifications. Roadway system classification is a tool used by engineers, planners, and elected officials that helps to design roadways and set expectations of how roadways will be used and operated. The Interstate, US Route, and Minnesota Trunk Highway network has been largely designed to connect large and distant areas of the state, move large vehicles, and move large volumes of traffic (Interstates were not included in these analyses because there are no two-lane two-way Interstates). The County State Aid System (CSAH) and County Road (CR) network has been designed to provide mobility for shorter (county-wide) trips, along with more direct access to businesses, residential developments, and communities within a county. Municipal and Township systems have largely been developed to provide access to residential, commercial, and agricultural uses.

Using these classifications, engineers and planners can understand which parts of the network are overused or underperforming compared to similar facilities. This can help to allocate resources and identify needed improvements.

When analyzing based on roadway system classification, over 63% of the fatal head-on crashes occur on US and MN Trunk Highways. These two classification systems comprise less than 8% of all roadways in Minnesota.

When adding in the CSAH system, these three roadway system classifications make up nearly 95% of the fatal head-on crashes on two lane highways in Minnesota. These three classifications make up 29% of the total roadway miles in Minnesota.

Table 3: System Classification for Fatal Head-On Crashes and Fatalities on Minnesota two-lane two-way Highways (2009-2013)

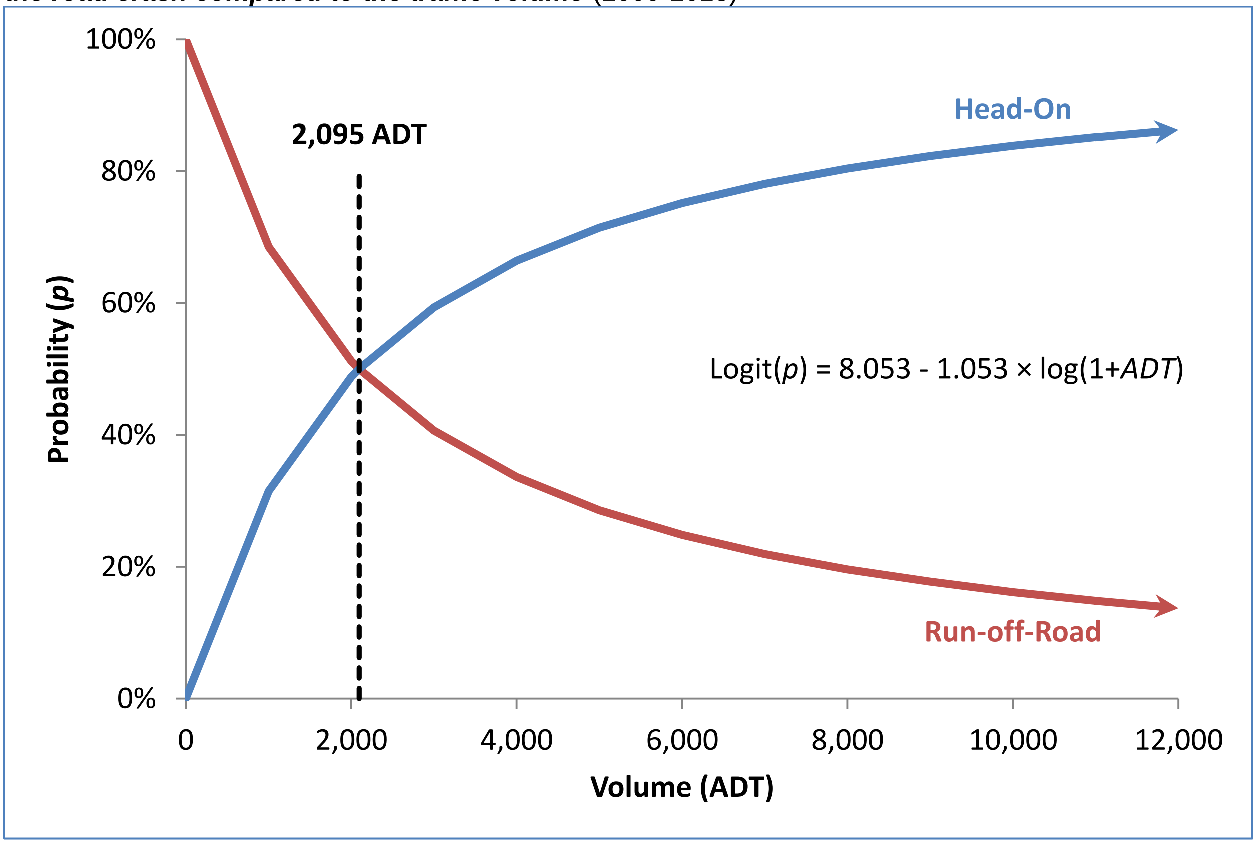
System Class	Number of Fatal Crashes	Number of Fatalities	Percent (%) of Total
US Route Trunk Highway	57	70	22.7%
Minnesota (MN) Trunk Highway	102	131	40.6%
County State Aid Highway (CSAH)	79	104	31.5%
Municipal State Aid Highway (MSAS)	3	3	1.2%
County Road (CR)	4	7	1.6%
Township	6	6	2.4%

Source: MnCMAT, June 2014.

Traffic Volumes

The traffic volume of a roadway is an effective predictor of a head-on crash occurring. This study examined the traffic volumes to identify patterns between the fatal crashes and the corresponding traffic volume. As Figure 2 shows, there is a non-linear relationship between volume and fatal head-on crashes. Crash records were matched with the average daily traffic (ADT) of the roadway. See Appendix F for more information.

Figure 2: Logistical Regression estimating the probability of a fatal head-on crash or fatal run off the road crash compared to the traffic volume (2009-2013)



Source: MnCMAT, June 2014. Minnesota Department of Transportation Office of Transportation Data and Analysis (MnDOT TDA), July 2014.

Traffic volumes were broken into categorical groups and each crash was placed into the appropriate grouping. Table 4 reveals the number of crashes becomes more important when compared to the number of miles within the state[1]. When the roadway miles are broken down to the same categories as the crash data above, the following cataloged miles are shown in Table 5.

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[1] MnDOT's Transportation and Data Analysis (TDA) keeps an inventory of most roads within Minnesota and their corresponding traffic volumes. The catalog includes nearly 59,000 miles of roadway. For more information regarding the data collection and methods used by TDA, the website is located at: http://www.dot.state.mn.us/traffic/data/coll-methods.html#TVPO

Table 4: Traffic Volumes (ADT) for Fatalities in Head-On Crashes on Minnesota two-lane two-way Highways (2009-2013)

Traffic Volume Range (ADT)	Number of Fatal Crashes	Number of Fatalities	Percentage of Fatal Crashes versus Total
0-400	15	19	6.0%
401-1,000	17	22	6.8%
1,001-2,000	37	50	14.8%
2,001-3,000	40	50	15.9%
3,001 – 5,000	77	93	30.6%
5,001-10,000	48	63	19.1%
10,001-15,000	10	17	4.0%
15,001-20,000	6	6	2.4%
20,001+	1	1	0.4%
Total	**251**	**321**	**100.0%**

Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Table 5: Number of miles of two-lane roadways in Minnesota, by traffic volume (ADT)

Traffic Volume Range (ADT)	Number of two-lane Miles	Percent of Cataloged Miles
0-400	29,336	51.4%
401-1,000	11,704	20.5%
1,001-2,000	6,925	12.1%
2,001-3,000	2,969	5.2%
3,001 – 5,000	3,091	5.4%
5,001-10,000	2,244	3.9%
10,001-15,000	550	1.0%
15,001-20,000	163	0.3%
20,001+	50	0.1%
Total	**57,034**	**100%**

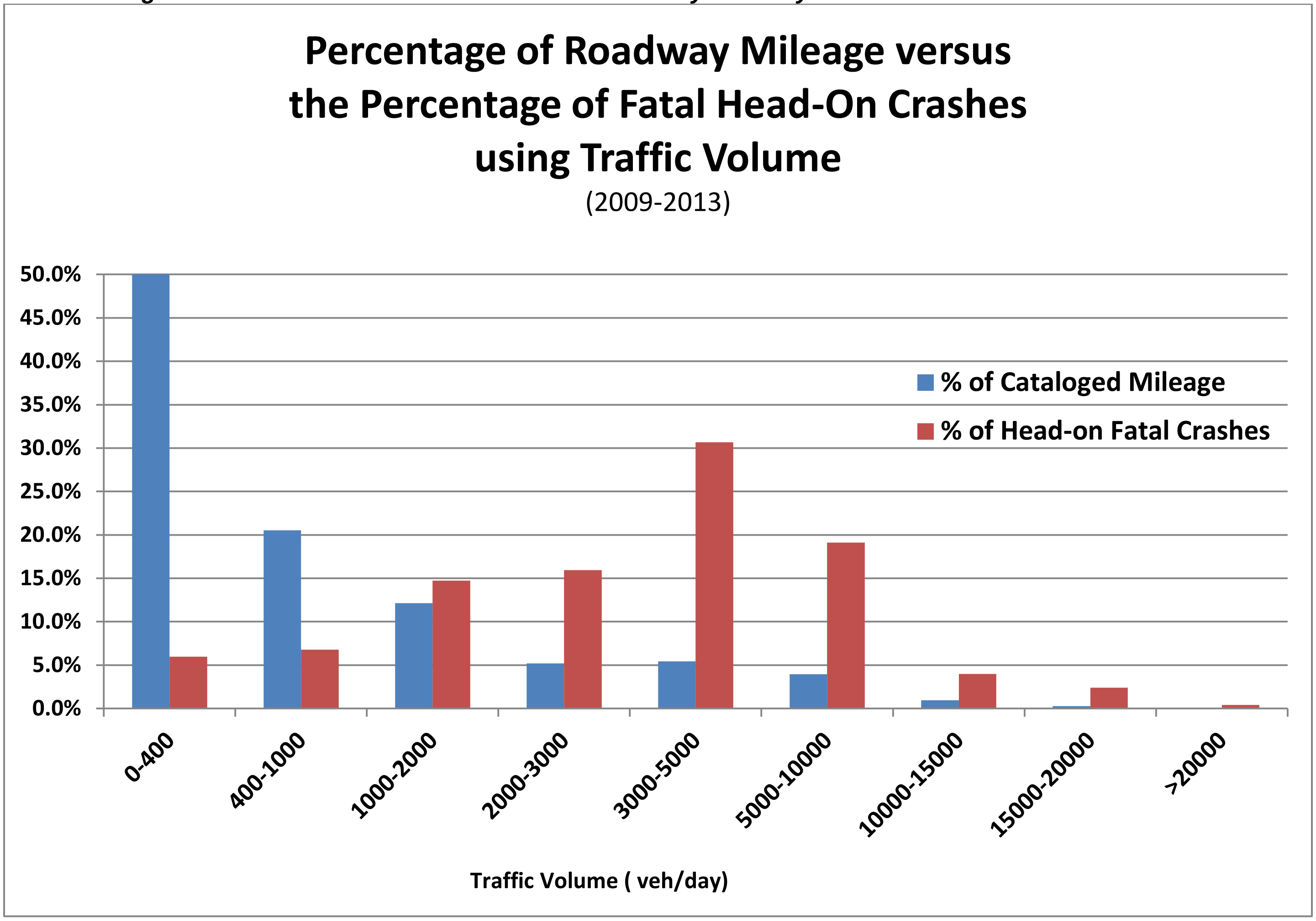
Source: MnDOT TDA, July 2014.

Comparing these two side by side, with the percentage of cataloged roadways compared to the percentage of fatal crashes is shown in Figure 3.[2]

Figure 3 shows that as the traffic volume rises, the percentage of fatal head-on crashes typically increases as well.

[2] Minnesota has over 142,000 miles of roadway. The majority of the roadways not cataloged are owned by municipalities (>20,000 miles) and townships (>60,000 miles). These roads tend to have a low traffic volume (ADT<200 vehicles/day). These roadways would change Figure 2 to have a much higher percentage of roads with an ADT <400.

Figure 3: Percentage of Roadway Mileage versus the Percentage of Fatal Head-On Crashes when using Traffic Volume on Minnesota two-lane two-way roadways



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

US and MN Trunk Highways

The Minnesota Trunk Highway Network accounts for less than 8% of the entire Minnesota roadway network, yet these roads carry over 40% of all the vehicle miles traveled.

Fatal crashes is mildly correlated with traffic volume ($r = +0.239$, p=0.063). Of the 201 people killed in head-on crashes on US and MN two-lane two-way Trunk Highways, 80% of fatalities (161 people) occurred on highways with traffic volumes above 2,000 ADT. These highways have a total length of 3,769 miles. See the Appendix F for more detailed information.

Table 6: Traffic Volumes (ADT) for Fatalities in Head-On Crashes on Minnesota two-lane two-way Trunk Highways (2009-2013)

Traffic Volume Range (ADT)	Number of Fatal Crashes	Number of Fatalities	Percentage of Total Fatal Crashes
0-400	1	1	0.6%
401-1,000	7	9	4.4%
1,001-2,000	23	30	14.5%
2,001-3,000	27	34	17.0%
3,001 – 5,000	62	74	39.0%
5,001-10,000	27	36	17.0%
10,001-15,000	5	10	3.1%
15,001-20,000	6	6	3.8%
20,001+	1	1	0.6%
Total	**159**	**201**	**100.0%**

Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

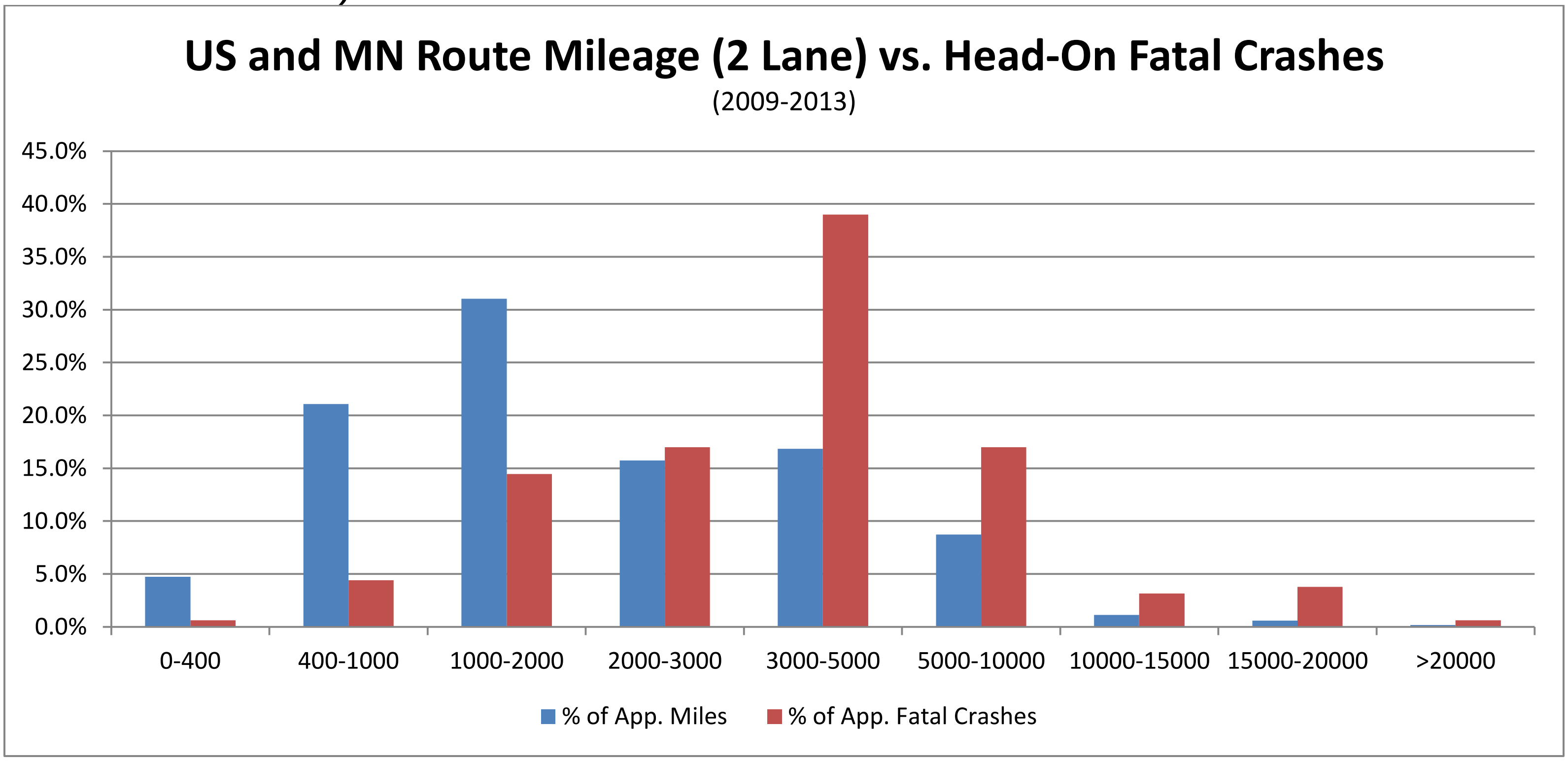
Table 7: Roadway miles of Minnesota two-lane two-way Trunk Highways

Traffic Volume Range (ADT)	Number of Miles	Percent of Miles
0-400	412	4.7%
401-1,000	1,838	21.1%
1,001-2,000	2,707	31.0%
2,001-3,000	1,372	15.7%
3,001 – 5,000	1,470	16.8%
5,001-10,000	762	8.7%
10,001-15,000	99	1.1%
15,001-20,000	52	0.6%
20,001+	14	0.2%
Total	**8,726**	**100%**

Source: MnDOT TDA, July 2014.

On US and MN two-lane two-way Trunk Highways with an ADT above 2,000 vehicles per day account for only 2.5% of the roadway miles in Minnesota, but account for over 8% of all traffic fatalities in a given year.

Figure 4: Percentage of Trunk Highway Mileage versus the Percentage of Fatal Head-On Crashes when using Traffic Volume on Minnesota two-lane two-way Trunk Highways (US and MN Classification)



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Strategies to Address Head-On Crashes for US and MN Trunk Highways

The majority of fatal head-on crashes occur from drivers drifting or wandering into the opposing lane. An effort should be made to increase the visibility and awareness of each driver's respective lane. This includes:

Centerline Rumble Strips

Centerline Rumble Strips are indentations that are milled into the pavement near the center of the two opposing lanes of travel. They provide immediate auditory and tactile lane departure warning to the driver as the vehicle approaches and crosses the centerline. Centerline rumble strips effectively reduce fatal and severe injury crashes by 30-50% (Torbic, et al. 2009. NCHRP Report 641). Centerline Rumble Strips are one of the nine proven safety countermeasures according to the Federal Highway Administration (FHWA). Centerline Rumble strips are a low cost strategy; current construction costs are roughly $3,500 per mile. The noise caused by vehicles that cross centerline rumbles can produce intermittent, unpleasant noise that can impact residents proximal to centerline rumble strip installations. MnDOT is currently working to address this concern and is developing a rumble strip that produces less external noise.

6"-8" yellow lines in each direction

The typical pavement marking is 4" for the yellow centerline and the white edgeline. Widening the pavement marking can help to provide increased delineation and guidance for drivers in dark or adverse weather conditions. Recent studies have found a 10% or greater crash reduction (Carlson et al, 2013). The cost on the wider lines is around $600 per mile. Wider edgelines help drivers navigate the road, but provide no direct auditory or tactile feedback to alert the driver.

4 Foot Centerline Buffers where allowable

The 4-Foot Buffer is a widened centerline that keeps opposing traffic 4 feet apart. This allows high-speed vehicles some recovery space should they drift to the left. The buffer should contain rumble strips, but is not required. The pavement top does not need to be widened, and this typically only requires the redistribution of the pavement surface. Restriping and rumbles could cost as little as $6,000 per mile. This could cost significantly more if shoulders need to be reconstructed or reinforced to handle the lateral displacement of traffic. This strategy is still relatively new and has not been widely deployed.

Due to the number of these head-on fatal crashes, consideration should be given to allow the reallocation of pavement width (if wide enough) to create a buffer at the expense of decreasing shoulder width. On higher volume highways, the shoulder, cross slopes, and clear zone offer safe and forgiving roadsides. Drivers who drift off the road to the right have considerable distance to slow down, recover, and stop while having little immediate danger. However, when drifting to the left, drivers immediately face the danger of high-speed oncoming traffic with little or no time to react. For the driver in the opposing lane, the crash often comes without warning or time to veer to safety.

On US and MN two-lane two-way Trunk Highways, 201 people have been killed in head-on crashes from 2009-2013. Ninety-five have been killed in road departure crashes to the right or left, 47 were to the right, 48 were to the left (MnCMAT, September 2014). Nearly 60% of these run off the road fatalities occurred on highways with a traffic volume below 2,000 vehicles/ day.

These deaths emphasize the need to categorize highways based on the type of risk they present to the drivers. On highways with an ADT less than 2,000 vehicles/day, designers should engineer the roadside to be more forgiving and to alert drivers that they are departing the roadway into danger (edgeline rumble strips).[3]

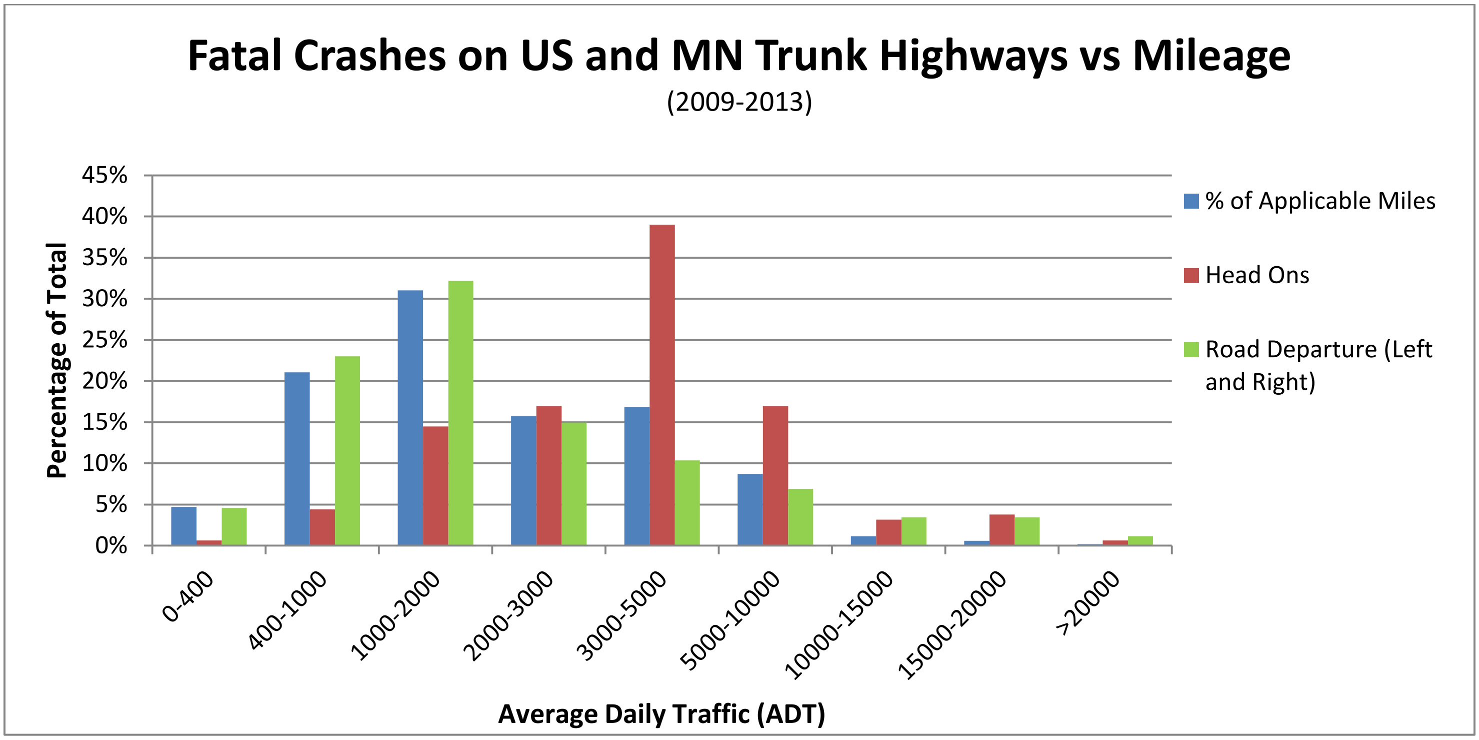
Once traffic volumes exceed 2,000 vehicles/day, safety strategies should focus on cross centerline crash prevention and injury risk reduction.

Figure 5: US 212 in western Minnesota. This picture helps to highlight the risk of injury for a driver departing the road to the right (low risk) versus departing into the opposing lane into an oncoming vehicle (high risk)

Source: MnDOT VideoLog 2013.

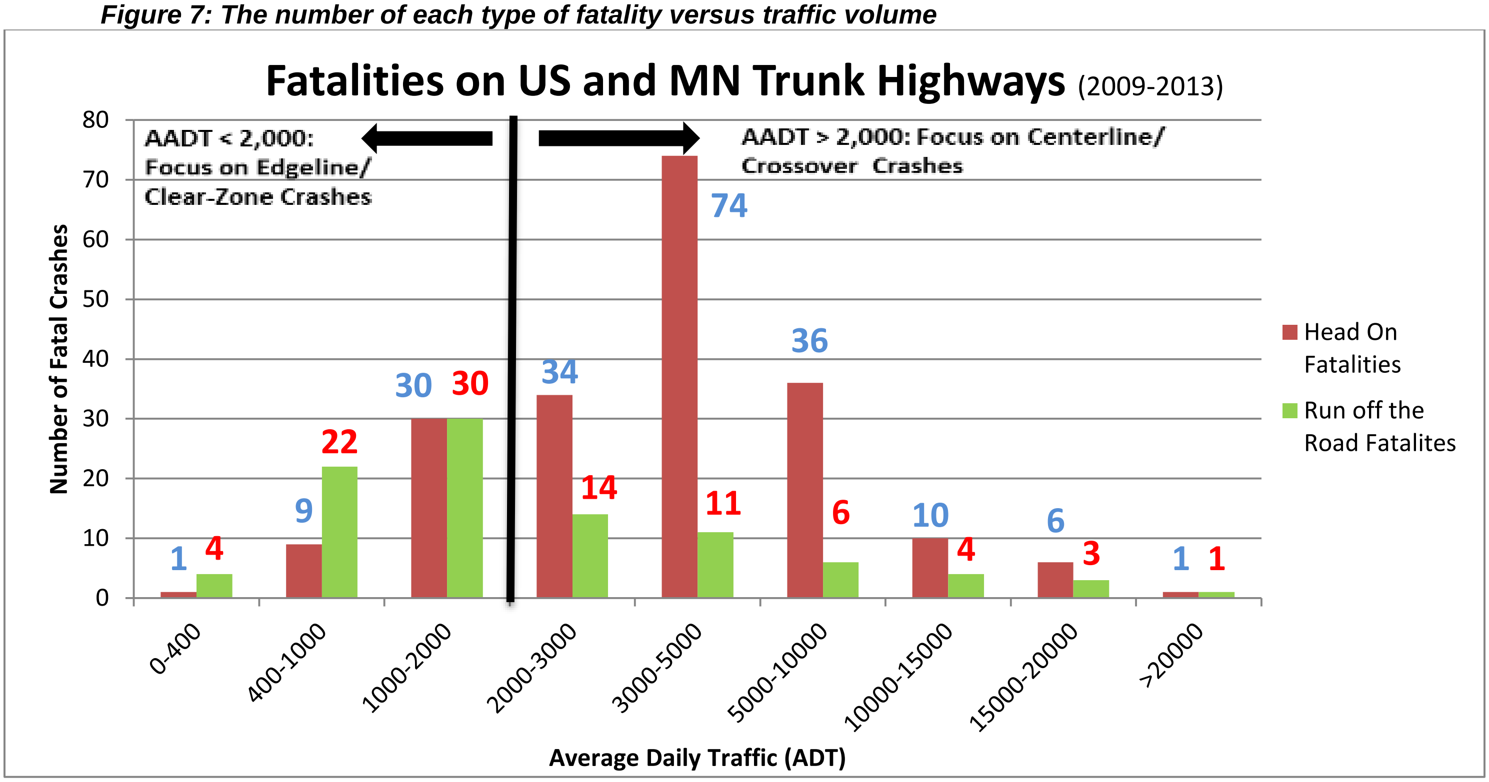
[3] Just to note: it is likely that most highway agencies, including MnDOT, are doing a good job of constructing and maintaining forgiving roadsides, especially for higher volume roads. However it still appears that most roads are at risk for high severity road departure regardless of the traffic volume on the road.

Figure 6: A comparison of the percentage of US and MN two-lane two-way Highways by traffic volume versus the percentage of fatal head-on crashes and the percentage of fatal road departure crashes



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Figure 7: The number of each type of fatality versus traffic volume



Source: MnCMAT, June 2014. MnDOT TDA, July 2014.

Centerline Rumble Strips' Impact on Fatal Crashes

A review of the seven (7) fatal crashes related to a passing maneuver revealed that none of the crashes occurred where centerline rumble strips were in place at the time of the crash. Most of the fatal passing crashes (6 out of 7) occurred on highways with a traffic volume greater than 3,000 vehicles per day.

144 of the 159 fatal head-on crashes (91%) occurred where no centerline rumble strips were present at the time of the crash. It is currently estimated that around 5-10% of Minnesota's two lane trunk highways have centerline rumble strips (CLRS). With the limited number of fatal head-on crashes crossing centerline rumble strips and the low percentage of two-lane trunk highways with centerline rumble strips, this metric does not show a strong connection either way. However, when reviewing crash performance of roads with centerline rumble strips versus those that do not have centerline rumble strips in place, a difference is noted. See Table 8.

Table 8: A comparison of segments with and without centerline rumble strips (2009-2013)

Description	**Crash Rate With CLRS**	**Crash Rate Without CLRS**	**Difference**
All Fatal and Severe Crash Rates	0.47 Severe Crashes/ 100 Million Vehicle Miles Traveled	1.72 Severe Crashes/ 100 Million Vehicle Miles Traveled	**- 72.7%**
All Crashes Rate	0.23 Crashes/ 1 Million Vehicle Miles Traveled	0.38 Crashes/ 1 Million Vehicle Miles Traveled	**- 39.5%**

Benefit to Cost of Implementing Rumble Strips

Before recommending centerline rumbles on US and MN trunk highways, a benefit/cost ratio should be calculated. It is important to note that this is using only fatal crashes (all crashes will be calculated after).

This analysis supports the recommendation of centerline rumble strips being placed on all rural, two-lane two-way US and MN trunk highways with an ADT above 2,000 vehicles/day. See the Appendix A-D for more information.

Total Number of Miles: 3,769 miles

Cost per Mile: $3,500

Total Implementation Cost: $13,192,000

Total Number of Fatal Crashes (5 years): 128

Societal Cost per Fatal Crash: 2 x Injury Type A = $1,100,000
(http://www.dot.state.mn.us/planning/program/appendix_a.html)

Societal Cost of Target Fatal Crashes: $140,800,000

Life Expectancy of Centerline Rumble: 7 Years

Crash Reduction Factor: 45% (http://www.cmfclearinghouse.org/detail.cfm?facid=3360)

Societal Cost Savings: $140,080,000 X 7 years/5 years X 0.45 = $88,704,000

Total Benefit/Cost Ratio = 6.3 *(Just on Fatal Crashes, adjusted for inflation)*

Potential Fatal Crashes Prevented (7 years) = 80-81 fatal crashes (80-105 fatalities)

With All Crashes: B/C Ratio = 12.3 (See Appendix B for more details)

Even if the cost of centerline rumble strips increased in price, or they were not as effective as stated, they would still provide benefits above the installation cost. (See Appendix C&D)

Recommendations

Based on the high number of fatal crashes on US and MN two-lane two-way Trunk Highways, it is recommended that highways with a traffic volume above 2,000 vehicles/ day should have centerline rumble strips installed as soon as possible. Highways with lower traffic volumes could also benefit from centerline rumble strips. Counties with similar highways should be following these practices as well. Once all the centerline rumbles are installed, there is a potential to prevent around 15 fatal crashes each year on just US and MN Trunk Highways. The societal crash savings from the fatal crashes alone in one year would have the potential to cover the $13.2 Million construction cost.

The reduced cost to society only considers the application of centerline rumble strips. The addition of other traffic safety strategies (edgeline rumbles, intersection illumination, placing chevrons on curves, etc.) could result in even greater reductions to societal costs due to crashes. In addition, $13.2 Million is a high estimated project cost. When rumbles are added to mill and overlay, rehabilitation, and reconstruction projects, the cost per mile is below $3,500 per mile. The 2014 MnDOT Construction Bids averaged $0.15 per linear foot for rumble strips, or $1,600 per mile for centerline rumbles strips.

$13.2 Million constitutes a very small portion of MnDOT's overall construction budget, which often exceeds $1 Billion each year. Spread out over 5 years, the total cost would be less than 0.3% of the total construction budget per year.

Appendices

Appendices A: A Benefit/Cost ratio showing the reduction in fatal crashes only on two-lane two-way US and MN Trunk Highways with a traffic volume greater than 2,000 vehicles per day. The crash data is from 2009-2013.

HSIP worksheet	Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
			Statewide, US and MN Two Lane Highways, ADT>2,000				1/1/2009	12/31/2013
	Description of Proposed Work		Centerline Rumbles on all US and MN Two Lane Highways, Fatal Crashes Only					

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						128			128
	Personal Injury (PI)	A									
		B									
		C									
	Property Damage	PD									
% Change in Crashes	Fatal	F						-45%			
	PI	A									
*Use Crash Modification Factors Clearinghouse		B									
		C									
	Property Damage	PD									
Change in Crashes	Fatal	F						-57.60			-57.60
	PI	A									
= No. of crashes X % change in crashes		B									
		C									
	Property Damage	PD									

		Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
Year (Safety Improvement Construction)	2015					
Project Cost (exclude Right of Way)	$ 13,192,000					
Right of Way Costs (optional)	$ -	F	-57.60	-11.52	$ 1,100,000	$ 12,672,000
Traffic Growth Factor	1%	A			$ 550,000	
Capital Recovery		B			$ 160,000	
1. Discount Rate	3.0%	C			$ 81,000	
2. Project Service Life (n)	7	PD			$ 7,400	
		Total				$ 12,672,000

B/C= 6.34

Using present worth values,

B= $ 83,700,791

C= $ 13,192,000

See "Calculations" sheet for amortization.

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Appendices B: A Benefit/Cost ratio showing the effect of centerline rumble strips on all crashes on all US and MN two-lane two-way Trunk Highways. The crash data is from 2009-2013.

HSIP worksheet	Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
			Statewide, ALL US and MN Two Lane Highways				1/1/2009	12/31/2013
	Description of Proposed Work		Centerline Rumbles on all US and MN Two Lane Highways, All Crashes					

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						159			**159**
	Personal Injury (PI)	A						147			**147**
		B						429			**429**
		C						518			**518**
	Property Damage	PD						1461			**1461**
% Change in Crashes *Use Crash Modification Factors Clearinghouse	Fatal	F						-45%			
	PI	A						-45%			
		B						-45%			
		C						-45%			
	Property Damage	PD						-10%			
Change in Crashes = No. of crashes **X** % change in crashes	Fatal	F						**-71.55**			**-71.55**
	PI	A						**-66.15**			**-66.15**
		B						**-193.05**			**-193.05**
		C						**-233.10**			**-233.10**
	Property Damage	PD						**-146.10**			**-146.10**

		Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
Year (Safety Improvement Construction)	2015					
Project Cost (exclude Right of Way)	$ 30,541,000					
Right of Way Costs (optional)	$ -	F	-71.55	-14.31	$ 1,100,000	$ 15,741,000
Traffic Growth Factor	1%	A	-66.15	-13.23	$ 550,000	$ 7,276,500
Capital Recovery		B	-193.05	-38.61	$ 160,000	$ 6,177,600
1. Discount Rate	4.5%	C	-233.10	-46.62	$ 81,000	$ 3,776,220
2. Project Service Life (n)	7	PD	-146.10	-29.22	$ 7,400	$ 216,228
		Total				$ 33,187,548

B/C= 6.88

Using present worth values,

B= $ 210,230,631

C= $ 30,541,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Technology
September 2014

Appendices C: A Benefit/Cost ratio showing the effect of centerline rumble strips on all crashes on all US and MN two-lane two-way Trunk Highways and if centerline rumbles (or an equally effective treatment) costs significantly more than the current planning level cost. This would mean centerline rumbles costing $12,000 per mile. The B/C is still above 2. The crash data is from 2009-2013.

HSIP worksheet	Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
			Statewide, ALL US and MN Two Lane Highways				1/1/2009	12/31/2013
	Description of Proposed Work		Centerline Rumbles on all US and MN Two Lane Highways, All Crashes, if centerline rumbles cost $12,000 per mile					

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						159			**159**
	Personal Injury (PI)	A						147			**147**
		B						429			**429**
		C						518			**518**
	Property Damage	PD						1461			**1461**
% Change in Crashes *Use Crash Modification Factors Clearinghouse	Fatal	F						-45%			
	PI	A						-45%			
		B						-45%			
		C						-45%			
	Property Damage	PD						-10%			
Change in Crashes = No. of crashes **X** % change in crashes	Fatal	F						**-71.55**			**-71.55**
	PI	A						**-66.15**			**-66.15**
		B						**-193.05**			**-193.05**
		C						**-233.10**			**-233.10**
	Property Damage	PD						**-146.10**			**-146.10**

		Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit	
Year (Safety Improvement Construction)	**2015**						
Project Cost (exclude Right of Way)	**$ 104,712,000**						**B/C= 2.01**
Right of Way Costs (optional)	**$ -**	**F**	**-71.55**	**-14.31**	**$ 1,100,000**	**$ 15,741,000**	*Using present worth values,*
Traffic Growth Factor	**1%**	**A**	**-66.15**	**-13.23**	**$ 550,000**	**$ 7,276,500**	**B= $ 210,230,631**
Capital Recovery		**B**	**-193.05**	**-38.61**	**$ 160,000**	**$ 6,177,600**	**C= $ 104,712,000**
1. Discount Rate	**4.5%**	**C**	**-233.10**	**-46.62**	**$ 81,000**	**$ 3,776,220**	*See "Calculations" sheet for amortization.*
2. Project Service Life (n)	**7**	**PD**	**-146.10**	**-29.22**	**$ 7,400**	**$ 216,228**	
		Total				**$ 33,187,548**	**Office of Traffic, Safety and Technology September 2014**

Appendices D: A Benefit/Cost (B/C) ratio showing the effect of centerline rumble strips on all crashes on US and MN two-lane two-way Trunk Highways and if centerline rumbles were not as effective as claimed by present research. If centerline rumbles had only a 15% injury crash reduction and 10% property damage crash reduction, the B/C is still above 2. The crash data is from 2009-2013.

HSIP worksheet

Control Section	T.H. / Roadway	Location	Beginning Ref. Pt.	Ending Ref. Pt.	State, County, City or Township	Study Period Begins	Study Period Ends
		Statewide, ALL US and MN Two Lane Highways				1/1/2009	12/31/2013

Description of Proposed Work: Centerline Rumbles on all US and MN Two Lane Highways, All Crashes, and if centerline rumbles only had a 15% injury crash reduction and a 3.3% property damage crash reduction. (1/3rd as effective)

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						159			159
	Personal Injury (PI)	A						147			147
		B						429			429
		C						518			518
	Property Damage	PD						1461			1461
% Change in Crashes *Use Crash Modification Factors Clearinghouse	Fatal	F						-15%			
	PI	A						-15%			
		B						-15%			
		C						-15%			
	Property Damage	PD						-3%			
Change in Crashes = No. of crashes **X** % change in crashes	Fatal	F						-23.85			-23.85
	PI	A						-22.05			-22.05
		B						-64.35			-64.35
		C						-77.70			-77.70
	Property Damage	PD						-48.65			-48.65

Year (Safety Improvement Construction)	2015
Project Cost (exclude Right of Way)	$ 30,541,000
Right of Way Costs (optional)	$ -
Traffic Growth Factor	1%
Capital Recovery	
1. Discount Rate	4.5%
2. Project Service Life (n)	7

Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
F	-23.85	-4.77	$ 1,100,000	$ 5,247,000
A	-22.05	-4.41	$ 550,000	$ 2,425,500
B	-64.35	-12.87	$ 160,000	$ 2,059,200
C	-77.70	-15.54	$ 81,000	$ 1,258,740
PD	-48.65	-9.73	$ 7,400	$ 72,004
Total				$ 11,062,444

B/C= 2.29

Using present worth values,

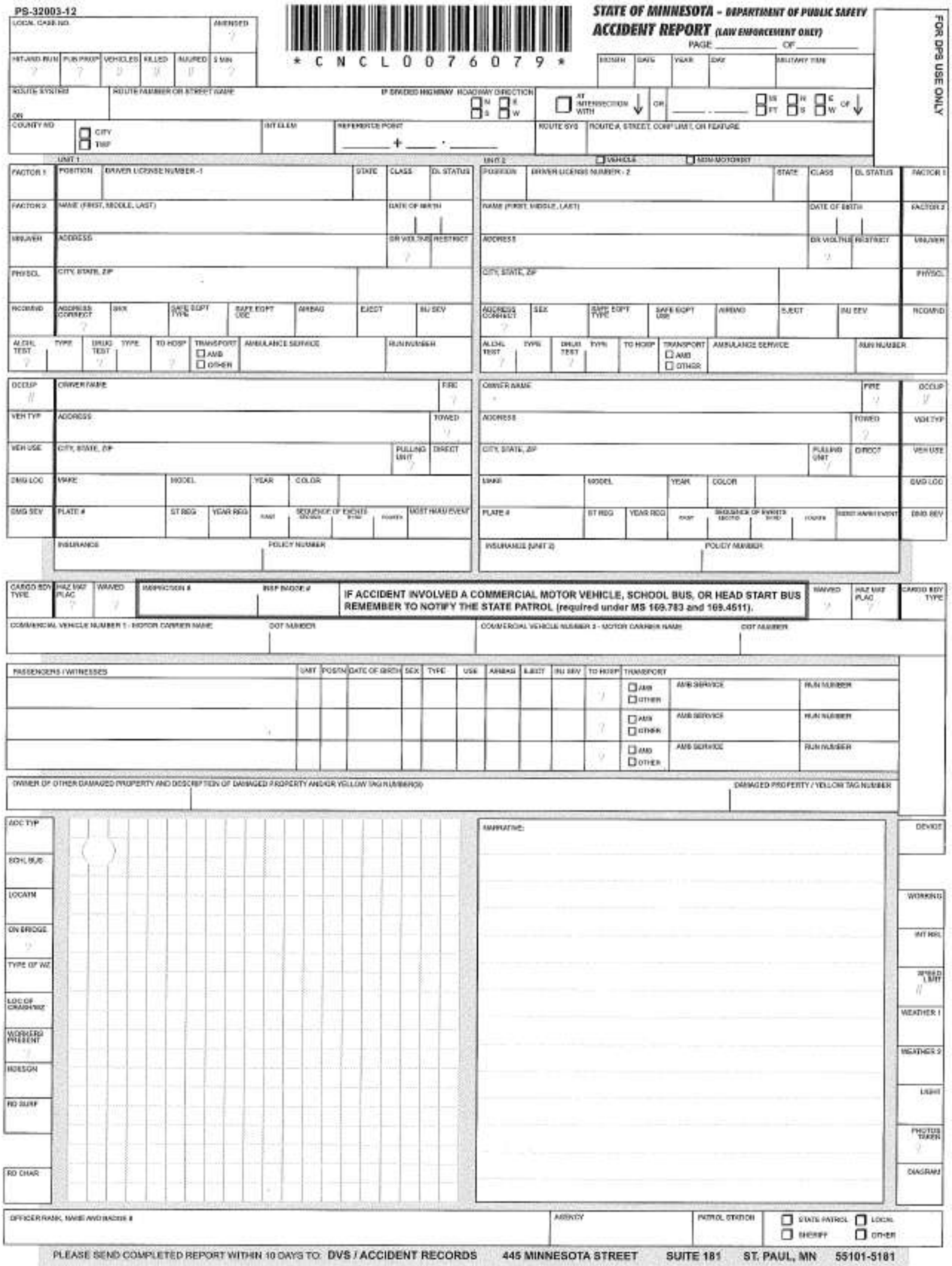
B= $ 70,076,420

C= $ 30,541,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Technology
September 2014

Appendices E: An example of the crash report form used in Minnesota.



PS-32003-12

STATE OF MINNESOTA - DEPARTMENT OF PUBLIC SAFETY

ACCIDENT REPORT (LAW ENFORCEMENT ONLY)

PAGE ____ OF ____

FOR DPS USE ONLY

* C N C L 0 0 7 6 0 7 9 *

LOCAL CASE NO. | AMENDED | HIT-AND-RUN | PUB PROP | VEHICLES | KILLED | INJURED | 5 MIN | MONTH | DATE | YEAR | DAY | MILITARY TIME

ROUTE SYSTEM | ROUTE NUMBER OR STREET NAME | IF DIVIDED HIGHWAY ROADWAY DIRECTION N S E W | AT INTERSECTION WITH | OR

ON | COUNTY NO | CITY | TWP | INT ELEM | REFERENCE POINT | ROUTE SYS | ROUTE #, STREET, CORP LIMIT, OR FEATURE

UNIT 1 / UNIT 2 (VEHICLE / NON-MOTORIST)

FACTOR 1 | POSITION | DRIVER LICENSE NUMBER | STATE | CLASS | DL STATUS

FACTOR 2 | NAME (FIRST, MIDDLE, LAST) | DATE OF BIRTH

VIN/LVER | ADDRESS | DR VIOL | RESTRICT

PHYSCL | CITY, STATE, ZIP

RCOMND | ADDRESS CORRECT | SEX | SAFE EQPT TYPE | SAFE EQPT USE | AIRBAG | EJECT | INJ SEV

ALCHL TEST | TYPE | DRUG TEST | TYPE | TO HOSP | TRANSPORT AMB / OTHER | AMBULANCE SERVICE | RUN NUMBER

OCCUP | OWNER NAME | FIRE

VEH TYP | ADDRESS | TOWED

VEH USE | CITY, STATE, ZIP | PULLING UNIT | DIRECT

DMG LOC | MAKE | MODEL | YEAR | COLOR

DMG SEV | PLATE # | ST REG | YEAR REG | SEQUENCE OF EVENTS FIRST SECOND THIRD FOURTH | MOST HARM EVENT

INSURANCE | POLICY NUMBER | INSURANCE (UNIT 2)

CARGO BDY TYPE | HAZ MAT PLAC | WAIVED | INSPECTION # | INSP BADGE #

IF ACCIDENT INVOLVED A COMMERCIAL MOTOR VEHICLE, SCHOOL BUS, OR HEAD START BUS REMEMBER TO NOTIFY THE STATE PATROL (required under MS 169.783 and 169.4511).

COMMERCIAL VEHICLE NUMBER 1 - MOTOR CARRIER NAME | DOT NUMBER | COMMERCIAL VEHICLE NUMBER 2 - MOTOR CARRIER NAME | DOT NUMBER

PASSENGERS / WITNESSES | UNIT | POSTN | DATE OF BIRTH | SEX | TYPE | USE | AIRBAG | EJECT | INJ SEV | TO HOSP | TRANSPORT AMB / OTHER | AMB SERVICE | RUN NUMBER

OWNER OF OTHER DAMAGED PROPERTY AND DESCRIPTION OF DAMAGED PROPERTY AND/OR YELLOW TAG NUMBER(S) | DAMAGED PROPERTY / YELLOW TAG NUMBER

ACC TYP | SCHL BUS | LOCATN | ON BRIDGE | TYPE OF WZ | LOC OF CRASH/WZ | WORKERS PRESENT | RDESGN | RD SURF | RD CHAR

NARRATIVE:

DEVICE | WORKING | INT REL | SPEED LIMIT | WEATHER 1 | WEATHER 2 | LIGHT | PHOTOS TAKEN | DIAGRAM

OFFICER RANK, NAME AND BADGE # | AGENCY | PATROL STATION | STATE PATROL | LOCAL | SHERIFF | OTHER

PLEASE SEND COMPLETED REPORT WITHIN 10 DAYS TO: DVS / ACCIDENT RECORDS 445 MINNESOTA STREET SUITE 181 ST. PAUL, MN 55101-5181

Appendices F: Fatal Head-On / Run-off-Road Analysis

2009-2013 Trunk Highway Crashes

1. Logistic Regression

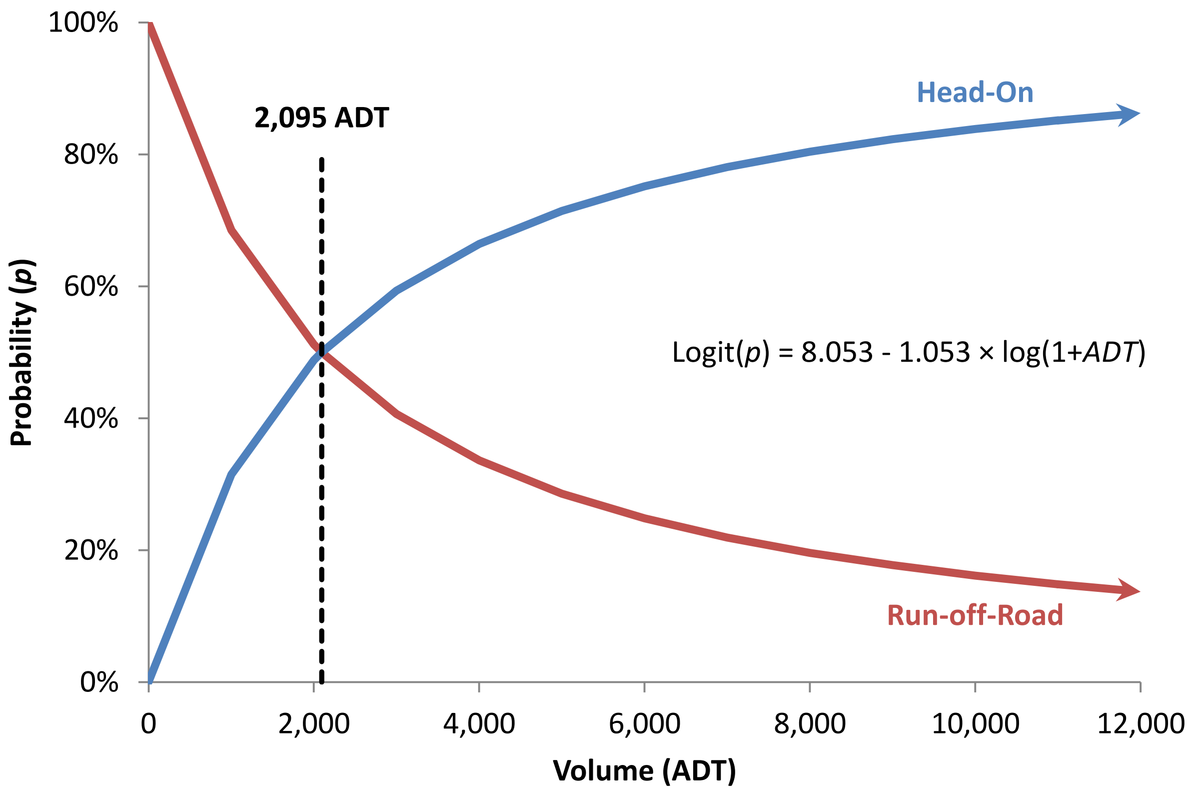
Logistic regression is performed to understand the likelihood of an event occurring given a defined environment. In this case, we are looking at the probability of a run-off-road crash among fatal lane departure crashes.

The model coefficients are estimates for the impact on the odds ratio. If the odds ratio is greater than 1, then run-off-roads are more likely than head-ons.

2. Model Estimates

Variable	Coefficient	Std. Error	Significance
[Constant]	8.053	.099	**.000**
Log ADT	-1.053	.744	**.000**

Despite the relatively simple model, this correctly classifies 77% of all fatal lane departure crashes by volume alone! As ADT increases, Log ADT increases. This in turn leads to a 65% decrease in the odds of a run-off-road crash given a fatal lane departure crash has occurred.[4]



[4] To get this, you take the 1 minus the exponential of the coefficient, i.e. *1 – EXP(-1.053) = 65%.*

3. Comparison of Lane Departure to Volume

Using the derived model, there is a natural break-point where it is equally likely that a fatal lane departure will be head-on or run-off-road. This occurs at 2,095 vehicles.

Fatal lane departure crashes

ADT Range	Head-Ons		Run-off-Roads		Lane Departures
0 to 2,095	73	21%	272	79%	345
2,096 to	178	73%	66	27%	244

When roadway volume ranges from zero to 2,095, there are 3.7 times more RUN-OFF-ROAD fatal crashes than head-on; for roads over 2,095, there are 2.7 times more HEAD-ONs than run-off-road fatal crashes.

Sources

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