Minnesota Department of Transportation
Office of Traffic, Safety, and Technology
1500 West County Road B-2
Roseville, MN 55113
Phone: 651/234-7388
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Date: February 4, 2011

Hari Kalla
Acting Director, Office of Transportation Operations
Federal Highway Administration
Office of Transportation Operations
1200 New Jersey Avenue, S.E., HOTO-1
Washington, DC 20590

RE: Request to Experiment – Converging Chevrons – St. Louis County, MN

Dear Mr. Kalla:

In accordance with the 2009 Manual on Uniform Traffic Control Devices (MUTCD), I am requesting permission to experiment with the above traffic control device. Under the authority of the MUTCD, the Minnesota Department of Transportation (Mn/DOT) has authorized and published a Minnesota version of this manual (MN MUTCD). The current MN MUTCD edition is dated July, 2005.

St. Louis County did a corridor safety analysis on Midway Road from U.S. Hwy 2 to Trunk Highway (T.H.) 194 in 2010. The intersection at Maple Grove Road (CSAH 6) and Midway Road had the highest weighted severity index. As a result of this study and in conjunction with a programmed pavement rehabilitation project, the County plans to implement two experimental safety measures at this intersection to reduce the speeds of vehicles approaching this intersection on Midway Road– narrow lanes and converging chevrons.

Enclosed is the County's description of their project that further details these traffic control devices and their plan for monitoring and evaluating the devices.

Thank you for your time and attention in regards to this request.

Sincerely,

Janelle Anderson

Janelle Anderson, P.E.
Tort Claims and Traffic Standards Engineer
Office of Traffic, Safety, and Technology

Enclosures

cc:
Phil Forst – FHWA Minnesota Division
James T. Foldesi, Public Works Director/Highway Engineer
Will Stein – FHWA
Ken Johnson – Mn/DOT

FHWA Request to Experiment

Integrated Speed Reduction Treatment for Intersections (ISRTI)

Submitted by: St. Louis County Public Works Department

Date: 2/1/2011

1.0 Introduction

St. Louis County Public Works Department is scheduled to repave a segment of County State Aid Highway No. 13 (Midway Road), starting at U.S. Highway 2 and ending at State Trunk Highway 194 in 2011. Midway Road is located in the City of Hermantown. The City of Hermantown is located within the Duluth-Superior metropolitan area. In 2009, the estimated population of the City of Hermantown was 9,586 people[1]. Midway Road is classified as a minor arterial. It serves as the primary route to connect Interstate 35 with the City of Hermantown and surrounding townships. Additionally, it also connects Interstate 35 with U.S. Highway 2 and U.S. Highway 53. The estimated 2011 AADT ranges from 8,800 vehicles per day in the south half of the segment to 7,000 vehicles per day in the north half of the segment[2]. Midway Road is constructed as a rural section with 10 feet shoulders. Figure 1 displays a map of the segment of Midway Road planned for construction and the location of the proposed experiment. During the project planning, a review of intersection crashes for this corridor was performed to identify potential traffic safety countermeasures that could be implemented with the construction project.

Figure 1. Map of Project Area

1. US Census Bureau. http://www.census.gov/. Accessed January 27, 2011.
2. Minnesota Department of Transportation – Traffic Volumes Map. http://www.dot.state.mn.us/traffic/data/html/volumes.html. Accessed January 27, 2011

2.0 Traffic Analysis

The initial crash analysis was completed for the 10 year period of 2000 to 2009. Table 1 displays intersection crashes by crash severity starting with U.S. Highway 2 and ending with State Trunk Highway 194 in order of south to north[1]. It should be noted that the intersections of U.S. Highway 2 and State Trunk Highway 194 are controlled by a traffic signal. All other intersections on this segment are controlled by a two-way stop.

Table 1. 2000 to 2009 Midway Rd. Intersection Crash Summary

INTERSECTING ROAD	CRASH SEVERITY					TOTAL	WEIGHTED SEVERITY INDEX[A]
	K	A	B	C	N		
U.S. 2			1	9	7	17	28
Hermantown Rd.	1			2	3	6	12
Maple Grove Rd.		2	3	9	21	35	56
Jamebard Rd.			1			1	3
West Arrowhead Rd.			1	4	6	11	17
Hagberg Rd.					2	2	2
Rose Rd.			1	1		2	5
STH 194			5	7	11	23	40

A. See Appendix for calculation of the Weighted Severity Index.

The intersection of Midway Road and County State Aid Highway No. 6 (Maple Grove Road) experienced the highest number of crashes for the analysis period. Additionally, this intersection also experienced the highest Weighted Severity Index. This suggests that relative to the number of crashes experienced by an intersection on this corridor, the intersection of Midway Road and Maple Grove Road experienced a larger number of more severe crashes than all other intersections. Therefore, the intersection of Midway Road and Maple Grove Road was identified as a candidate to implement some type of traffic safety countermeasure.

The second phase of the crash analysis was to identify the predominant crash diagram. Figure 2 displays the chart of crashes by crash diagram that occurred at the intersection of Midway Road and Maple Grove Road for the same 10 year period of 2000 to 2009. As indicated by the chart, the predominant crash diagram is right-angle crashes. A collision diagram was also completed to identify the pattern of the right-angle crashes within the intersection. A copy of the collision diagram is included in the Appendix.

1. Minnesota Crash Mapping Analysis Tool (MnCMAT)

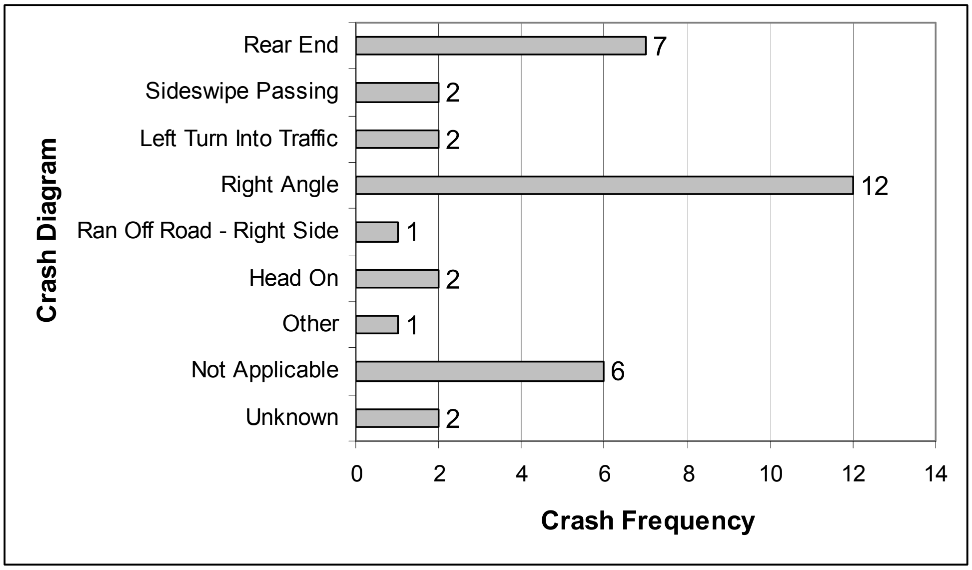

Figure 2. 2000 to 2009 Midway Rd. and Maple Grove Rd. Intersection Crashes by Crash Diagram

A turning movement count was performed at this intersection on April 8, 2010. A summary of the peak hour turning movement count is included in the Appendix. During the peak hour, there is a significant left turning movement from the east approach of Maple Grove Road. Due to the heavy traffic volume on Midway Road, the east approach of Maple Grove Road is currently experiencing an average delay of 26.5 seconds per vehicle which corresponds to a level of service D. See the Appendix for the Synchro report. A traffic signal warrant analysis was completed using the data from the 2010 turning movement count. For the year 2010, no traffic signal warrants were satisfied. For that year, Warrant 1A (Eight Hour Vehicular Volume – Minimum Volume) satisfied six of the eight hours required. Warrant 2 (Four Hour Vehicular Volume) satisfied three of the four hours required. A sensitivity analysis was performed to determine what year a traffic signal may be warranted using a twenty year growth factor of 1.2. From this analysis, 2018 was the first year that a warrant, Warrant 1A, was satisfied. In the year 2020, Warrant 1A, Warrant 2 and Warrant 3 (Peak Hour Volume) were satisfied. This suggests there may be a 10 to 15 year window before a traffic signal or other traffic control device is seriously considered. In the meantime, engineering judgment supports implementing a traffic safety countermeasure until a change in traffic control is completed.

Figure 3 displays the existing intersection lane configuration.

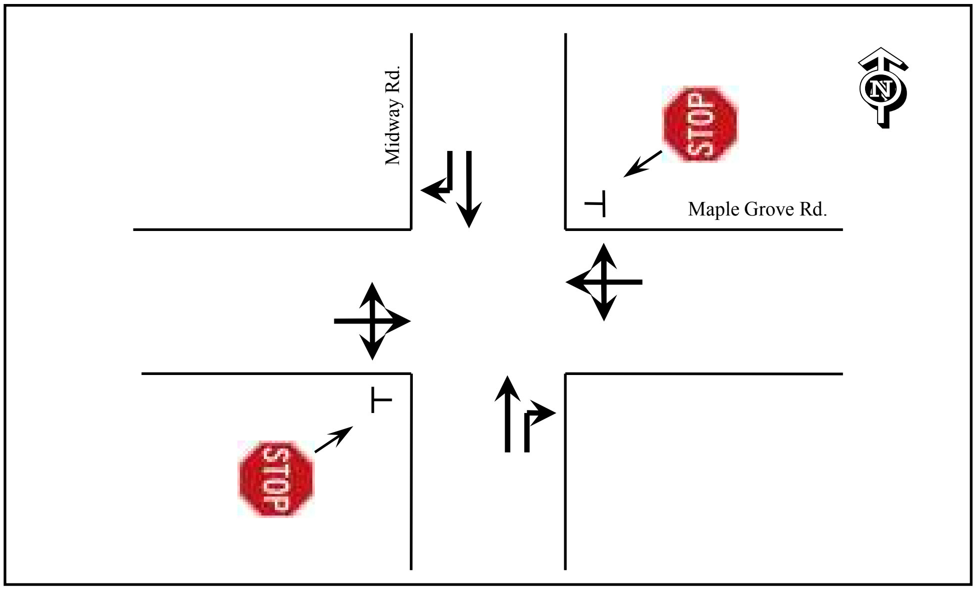

Figure 3. Midway Rd. and Maple Grove Rd. Intersection Lane Configuration

3.0 Proposed Experimental Improvement

St. Louis County researched potential improvements to reduce right-angle crashes. Two concepts were identified that by combining together have great potential to improve the intersection safety performance. The first concept is to implement lane narrowing on both major approaches. The second concept is to install converging chevrons within the traveled lanes on both major approaches. The following sections discuss each of these concepts and their observed performance.

3.1 Lane Narrowing Concept

At rural two-way stop controlled intersections, drivers stopped on the minor approach must be able to accurately estimate the available gap in the traffic stream on the major approaches. One of the contributing factors to right-angle crashes is due to the inability of a driver stopped on the minor approach to accurately estimate this gap. In this case, a driver on the minor approach may underestimate the "actual" gap and thereby select an insufficient gap to safely perform a turning maneuver resulting in a right-angle crash. Reducing vehicle speeds on the major approaches to an intersection has been identified as a strategy to improve intersection safety[1].

The first concept implements lane narrowing on both major approaches of an intersection. The standard lane width for a major County State Aid Highway is 12 feet. This concept reduces the lane width to nine or ten feet before the intersection. The objective of this concept is to reduce the speed of vehicles approaching the intersection on the major approaches. To enforce the narrow lane, this concept includes rumble strips in the center median and along the edgeline[2].

1. NCHRP Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions. 2003. Transportation Research Board. Washington, D.C.
2. Hughes W., Jagannathan R., Gross, F. 2008. *Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways*. Federal Highway Administration. Publication No. FHWA-HRT-08-063.

In a research project in Iowa, an experimental traffic calming treatment reduced lane widths to 10.0 feet to 10.5 feet with the objective to reduce vehicle speeds[1]. Figure 4 displays a schematic of the lane narrowing concept[2].

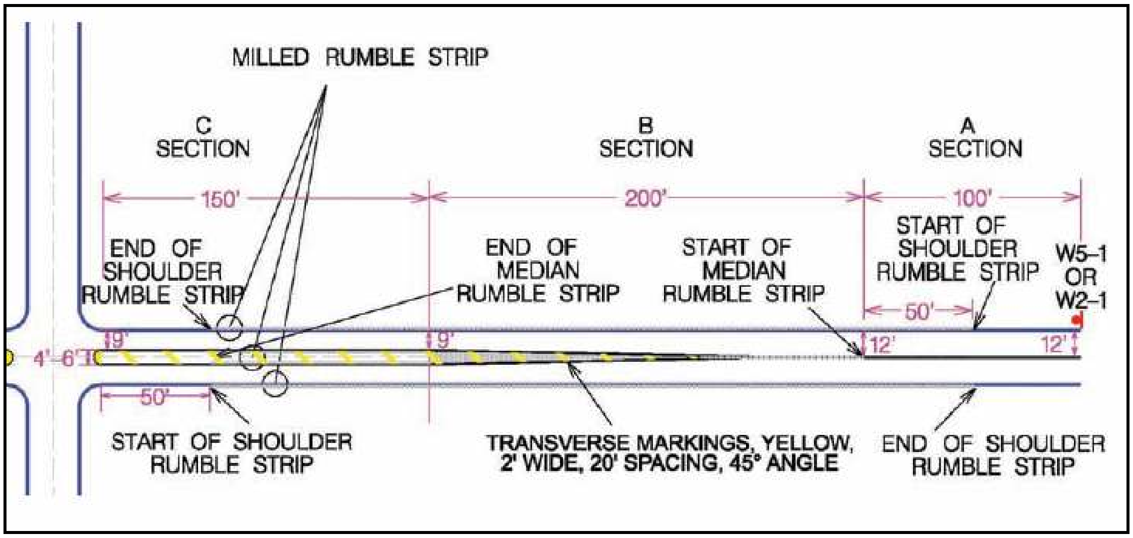

Figure 4. Lane Narrowing Concept Schematic

It was reported that after the implementation of the lane narrowing concept in nine locations in Pennsylvania, Kentucky, Missouri and Florida, there was an average reduction in vehicle speeds of 3.5 mph across all locations. The average reduction in the 85th percentile vehicle speeds was 4.5 mph across all locations. The crash analysis found an average reduction in the crash rates of 31 percent for total crashes, 20 percent for fatal and major injury crashes, and 42 percent of right-angle crashes. However, there was an average increase in the crash rate for rear-end crashes of 54 percent. It was hypothesized that speed differential, and turning and passing vehicles were the reasons for this increase in rear-end crashes. Finally, a statistical hypothesis test was performed on the total, and fatal and major injury crash rates for all locations included in the study. For the 95 percent confidence level, the reduction in total crash rate was not significant. However, at the same confidence level, there was a significant reduction in fatal and injury crashes[2].

As with any countermeasure, there will generally be some type of side effect. However, the goal of the practitioner is to balance those side effects with the benefits. In the case of the lane narrowing concept, there was a reduction in the right-angle crash rate by 42 percent and a statistically significant reduction in fatal and injury crashes. It should be noted that right-angle crashes generally result in higher severity crashes than rear-end crashes. And in the case of the intersection of Midway Road and Maple Grove Road, right-angle crashes were the dominate crash diagram.

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1. Hallmark S. et. al. 2007. *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities*. Center for Transportation Research and Education. Iowa State University.
2. Hughes W., Jagannathan R., Gross, F. 2008. *Two Low-Cost Safety Concepts for Two-Way STOP-Controlled, Rural Intersections on High-Speed Two-Lane, Two-Way Roadways*. Federal Highway Administration. Publication No. FHWA-HRT-08-063.

3.2 Converging Chevron Pattern Concept

The second concept is a converging chevron pattern. Figure 5 displays the schematic of the converging chevron pattern concept[1]. The key design of converging chevrons progressively decreases the distance between the chevrons and reduces the width of successive chevrons. When a driver traverses the converging chevron pattern, the design of the converging chevrons creates an illusion for the driver that the vehicle is traveling faster than it really is. As a result, drivers will tend to slow down their vehicle. A research project in Iowa installed converging chevrons on each end of a city as a gateway traffic calming treatment. The converging chevron pattern was designed to reduce vehicle speeds from 35 mph to 25 mph. The average speed reduction achieved over a 12 month period ranged from 0.4 mph to 1.3 mph for one location and 0.7 mph to 3.0 mph for another location. In many cases, the speed reductions were statistically significant at the 95 percent confidence level[1].

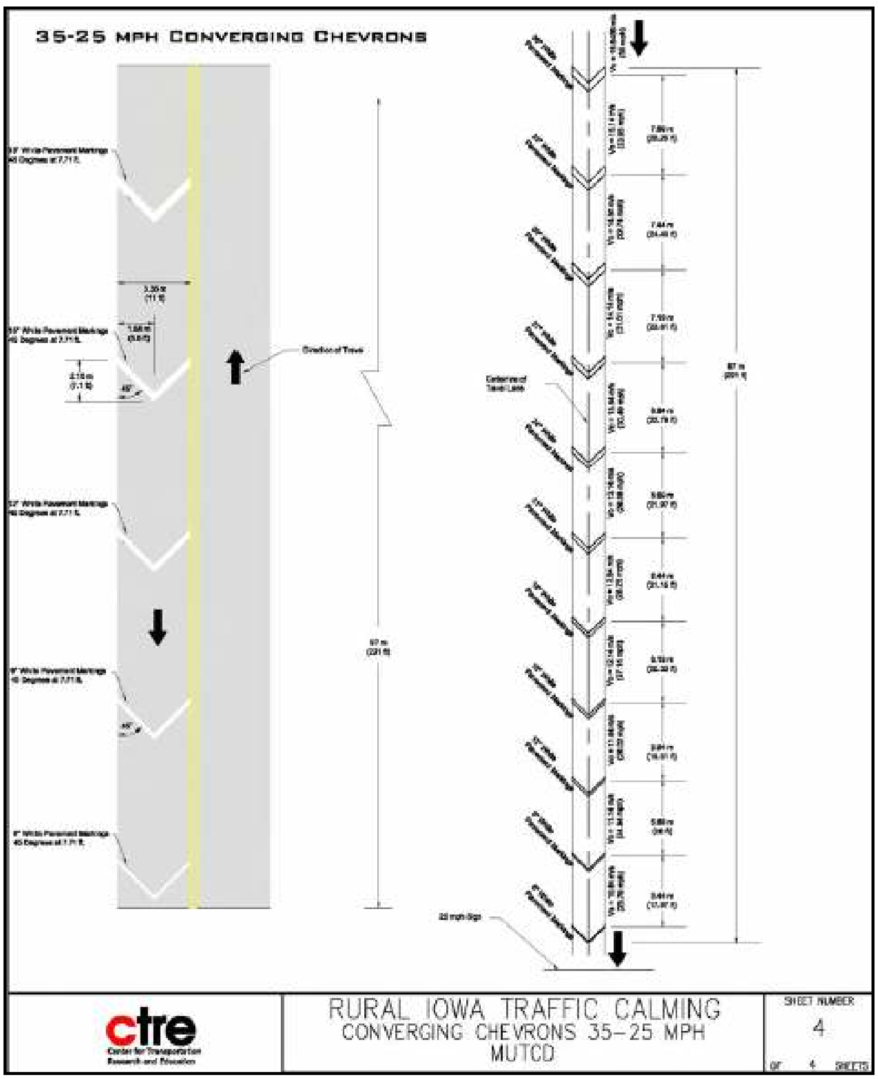


Figure 5. Converging Chevron Pattern Concept Schematic

1. Hallmark S. et. al. 2007. *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small Rural Communities*. Center for Transportation Research and Education. Iowa State University.

A research project in Minnesota also installed a converging chevron pattern and found a reduction in average vehicle speeds over a four year period of 1 mph to 6 mph for two directions of traffic. The 85th percentile speed for the same time period and travel directions was reduced by 1 mph to 7 mph[1].

4.0 St. Louis County Experimental Concept

St. Louis County proposes to implement an Integrated Speed Reduction Treatment for Intersections (ISRTI) by integrating the lane narrowing concept with the converging chevron pattern concept. One difference is that St. Louis County will not include rumble strips to enforce the narrow lanes due to noise concerns. It is hypothesized that incorporating the converging chevrons will enhance the speed reduction effect of the narrow lanes. The combined effects of the lane narrowing and converging chevron pattern is expected to effect, at a minimum, the same speed reduction benefit as the lane narrowing concept with the rumble strips. See the Appendix for the layout of the ISRTI at the intersection of Midway Road and Maple Grove Road.

4.1 St. Louis County Experimental Concept Design

The ISRTI will narrow both major approach lanes from 12 feet to 10.5 feet and place converging chevrons within the lane. The narrow lanes will result in a three feet wide median. The most complex aspect of creating this design was designing the converging chevrons. A method is available to determine the design parameters of the converging chevron pattern. This method was used to design the converging chevron pattern in Milwaukee, Wisconsin[2].

This method requires the determination of five variables to design the converging chevron pattern. The first and second variables are the design speed entering the converging chevron pattern and the design speed exiting the converging chevron pattern. St. Louis County designed the converging chevron pattern to reduce the speed of a vehicle from 55 mph to 45 mph. The third variable was to estimate a deceleration value due to braking. An initial effort to estimate deceleration with no braking was performed by driving a passenger vehicle at 55 mph and allowing the vehicle to decelerate by coasting (no brakes applied) to 45 mph over level terrain. For ten trial runs, the average time to decelerate was 12.3 seconds. The deceleration was then calculated to be 1.20 ft/sec^2. A deceleration due to braking of 3.30 ft/sec^2 was used for the Milwaukee design[2]. This deceleration value appeared to be too aggressive. Given the deceleration value of 1.20 ft/sec^2 due to coasting, the deceleration value of 2.50 ft/sec^2 was selected as a "best guess" given the relative benchmarks. The fourth variable was to identify the reaction time of a driver. The Milwaukee design used a reaction time of 0.5 seconds. This value appeared reasonable so it was used in this St. Louis County design. The fifth variable was to estimate the number of chevrons per second a vehicle would cross. The Milwaukee design used 2.2 chevrons/sec. Because there were no other reference points available in the literature search, this value was assumed reasonable and used in the St. Louis County design. See the Appendix for a detail of the design calculations.

1. Corkle J., Giese J. and Marti M. 2001. *Investigating the Effectiveness of Traffic Calming Strategies on Driver Behavior, Traffic Flow, and Speed*. Minnesota Local Road Research Board. Minnesota Department of Transportation.
2. Drakopoulos, A., Vergou, G. 2003. *Evaluation of the Converging Chevron Pavement Marking Pattern at one Wisconsin Location*. AAA Foundation for Traffic Safety.

The first calculation was to determine the length of the converging chevron pattern which was calculated as 472.6 feet. The second calculation was to determine the total time for a vehicle to travel the design length which was calculated as 6.50 seconds. The third calculation was to determine the total number of chevrons required. The number of chevrons required for each direction was calculated as 15 chevrons with 14 spaces. From these design parameters, the design velocity, distance and location could then be calculated. Table 2 displays these design parameters of the converging chevron pattern. Chevron 1 is the first chevron a vehicle crosses when approaching the intersection whereas Chevron 15 is the last chevron a vehicle crosses before entering the intersection. The velocity is the design velocity a vehicle will be traveling at immediately after crossing the respective chevron. For example, immediately upon crossing Chevron 5, the design velocity of a vehicle will be 77.37 ft/sec, or 52.6 mph. The distance between the chevrons will progressively decrease from 40.4 feet when a vehicle first enters the converging chevron pattern to 30.8 feet. There will be a distance of 60 feet between Chevron 15 and the near side edgeline of Maple Grove Road. The width of the chevrons will start at 32 inches and decrease at a rate of 2 inches per chevron to a width of 4 inches.

Table 2. Converging Chevron Design Parameters

Direction of Travel

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
Chevron 1	80.85	40.4	543	32
Chevron 2	80.85	37.3	503	30
Chevron 3	79.69	36.7	465	28
Chevron 4	78.53	36.2	429	26
Chevron 5	77.37	35.6	392	24
Chevron 6	76.21	35.1	357	22
Chevron 7	75.05	34.6	322	20
Chevron 8	73.89	34.0	287	18
Chevron 9	72.73	33.5	253	16
Chevron 10	71.57	32.9	220	14
Chevron 11	70.41	32.4	187	12
Chevron 12	69.25	31.9	154	10
Chevron 13	68.09	31.3	122	8
Chevron 14	66.92	30.8	91	6
Chevron 15	65.76	30.3	60	4
Intersection Offset			30	

4.2 St. Louis County Experimental Concept Expected Performance

As discussed in Section 3.1, the lane narrowing concept resulted in an average reduction of vehicle speeds of 3.5 mph. From Section 3.2, the converging chevron pattern appeared to result in a general reduction of vehicle speeds of 1 mph to 5 mph. It is unclear what effect the combination of lane narrowing and converging chevrons have on effect speed reduction. Based upon engineering judgment, it is assumed the ISRTI will effect a sustained reduction in vehicle speeds of 5 mph.

An estimate of the increase in gap time was then determined based upon this estimated reduction in vehicle speeds. Prior to the turning movement count, traffic counters were placed on Midway Road to determine the peak day to perform the turning movement count. This initial traffic count also provided average speed and average headway information. Using the relationship between flow, speed and density, the estimated increase in gap time could be determined. Two random 15 minute time periods were selected from the initial traffic count to be used as case studies. For the first case, there was a volume of 305 vehicles with an average speed of 41 mph and average headway of 2.94 seconds. In the second case, there was a volume of 121 vehicles and an average speed of 44 mph and average headway of 7.38 seconds. Using the estimated speed reduction of 5 mph, the average headway, or gap time, was increased in the first case by 0.41 seconds and in the second case by 0.93 seconds. See the Appendix for a detail of the gap calculations. As demonstrated by these two cases, the ISRTI is expected to increase gap time and therefore reduce the risk of a crash.

A benefit/cost analysis was completed to determine if the potential increase in rear-end crashes outweighs the benefit of reduced right-angle crashes. Utilizing the average reduction in the right-angle crash rate of 42 percent and an increase in the rear-end crash rate of 54 percent as crash reduction factors, the benefit/cost ratio was computed as 6.14. See the Appendix for a detail of benefit/cost analysis. It appears that ISRTI will have a significant overall safety benefit even with the potential increase in rear-end crashes.

Finally, a review of practical advantages and disadvantages of the ISRTI was completed. Some advantages identified were its low cost (estimated cost is $25,000), it is non-invasive to vehicles or nearby residents (no bumps therefore no noise), and roadway geometrics are not altered. Some disadvantages identified were the inability to view the pavement markings during winter due to snow cover, and that the pavement markings are subject to high-wear due to winter maintenance activities. To reduce wear, St. Louis County will utilize ground-in pavement markings.

5.0 Patent/Copyright Statement

St. Louis County is not aware of any pending or current patents or copyrights on either the lane narrowing concept or converging chevron pattern concept.

6.0 Evaluation Plan

St. Louis County will commit to performing an evaluation of the ISRTI at one year, two years and three years from implementation. This evaluation will include a “before and after” study utilizing crash and speed data. The crash analysis will include a comparison of total crashes, fatal and injury crashes, right-angle crashes and rear-end crashes. The speed analysis will include a comparison of vehicle speeds on the major approaches entering and leaving the pattern. Speed measurements will be performed immediately (days), one month, three month, six month, one year, two years and three years from implementation. The speed measurements are dependant upon weather conditions. If there is snow covering the roadway, the traffic counters cannot be deployed and vehicle speeds will not be normal due to winter weather conditions. Of interest to St. Louis County is whether a driver adaptation effect will be observed in which drivers return to “normal” driving behavior over time as indicated by comparable speeds to the before period.

The intent to restore the experimental site will be dependant upon the findings from the evaluation reports. If the evaluation reports suggest an improvement in traffic safety, St. Louis County will continue to maintain the ISRTI perpetually into the future. If safety concerns directly or indirectly related to the ISRTI are identified, or a different traffic control device such as a traffic signal is installed, St. Louis County will restore the intersection to a condition that complies with the Manual on Uniform Traffic Control Devices (MUTCD). St. Louis County recognizes that the Federal Highway Administration has the authority to terminate this experimental application at anytime and will hereby comply with any such order.

7.0 Conclusion

St. Louis County believes ISRTI has the potential to significantly improve traffic safety at rural two-lane, high speed intersections. If positive findings are documented from this experiment, St. Louis County would urge the Federal Highway Administration and Minnesota Department of Transportation to consider further evaluation of this concept with the intent of identifying it as an approved strategy in the MUTCD.

APPENDIX

WEIGHTED SEVERITY INDEX

Weighted Severity Index = (K x 5) + (A x 4) + (B x 3) + (C x 2) + N

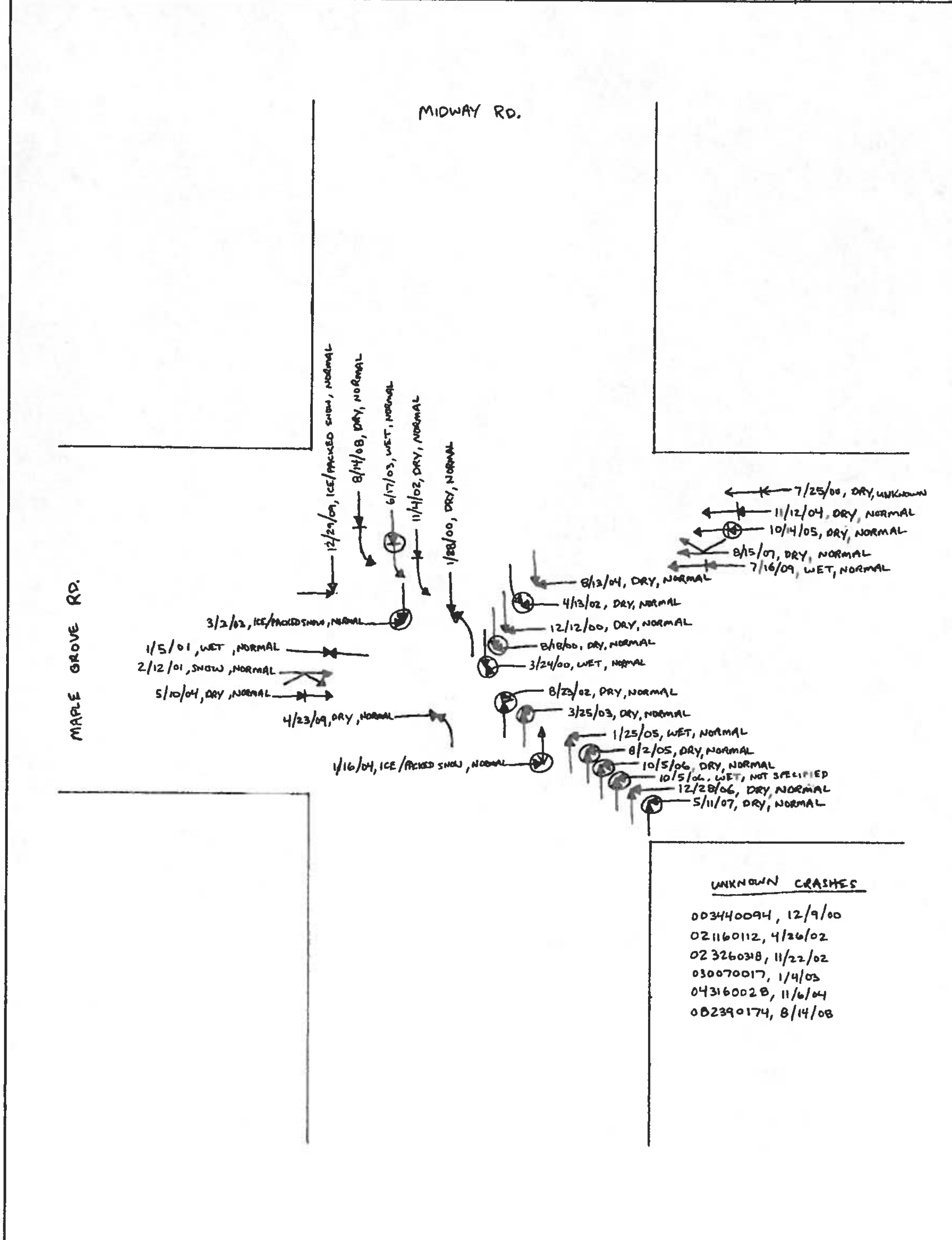
COLLISION DIAGRAM

COLLISION DIAGRAM

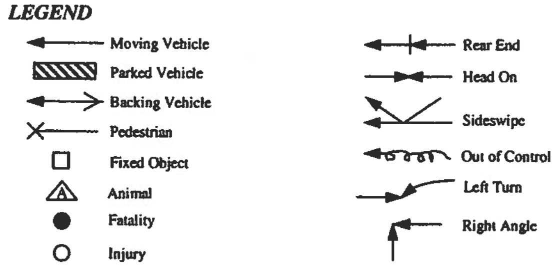
Location: MIDWAY RD. & MAPLE GROVE RD.

Period From: 1/1/2000 To: 12/31/2009

North Arrow



LEGEND



Identify for Each Crash

1. Approximate location of crash
2. Type of collision and vehicles involved
3. Light Conditions
4. Pavement condition (dry, wet, etc.)
5. Other pertinent factors (alcohol, drugs, vehicle failure, etc.)

PEAK HOUR TURNING MOVEMENT COUNT

Intersection	CSAH 13 and CSAH 6		Year = 2010
Count Date	4/8/2010		
Count Period	7:00 am to 8:00 pm		
Peak Hour	4:15 pm to 5:15 pm	Peak Hour Volume = 768	PHF = 0.923

CSAH 13 From North

Right	Thru	Left	Total Approach Volume
18	225	6	249

CSAH 6 From West

Left	Thru	Right	Total Approach Volume
4	20	8	32

CSAH 6 From East

Right	Thru	Left	Total Approach Volume
13	44	148	205

CSAH 13 From South

Left	Thru	Right	Total Approach Volume
7	193	82	282

SYNCHRO REPORT

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Volume (veh/h)	4	20	8	148	44	13	7	193	82	6	225	18
Peak Hour Factor	0.33	0.63	0.50	0.88	0.79	0.54	0.44	0.79	0.79	0.38	0.92	0.64
Hourly flow rate (veh/h)	12	32	16	168	56	24	16	244	104	16	245	28
Pedestrians												
Lane Width (ft)												
Walking Speed (ft/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
vC, conflicting volume	604	656	245	584	580	244	273			348		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	97	92	98	56	87	97	99			99		
cM capacity (veh/h)	350	375	794	380	415	794	1291			1211		

Direction, Lane #	EB 1	WB 1	NB 1	NB 2	SB 1	SB 2
Volume Total	60	248	260	104	260	28
Volume Left	12	168	16	0	16	0
Volume Right	16	24	0	104	0	28
cSH	430	409	1291	1700	1211	1700
Volume to Capacity	0.14	0.61	0.01	0.06	0.01	0.02
Queue Length (ft)	12	97	1	0	1	0
Control Delay (s)	14.7	26.5	0.6	0.0	0.6	0.0
Lane LOS	B	D	A		A	
Approach Delay (s)	14.7	26.5	0.4		0.5	
Approach LOS	B	D				

Intersection Summary			
Average Delay	8.1		
Intersection Capacity Utilization	44.5%	ICU Level of Service	A

EAST APPROACH DELAY = 26.5 sec

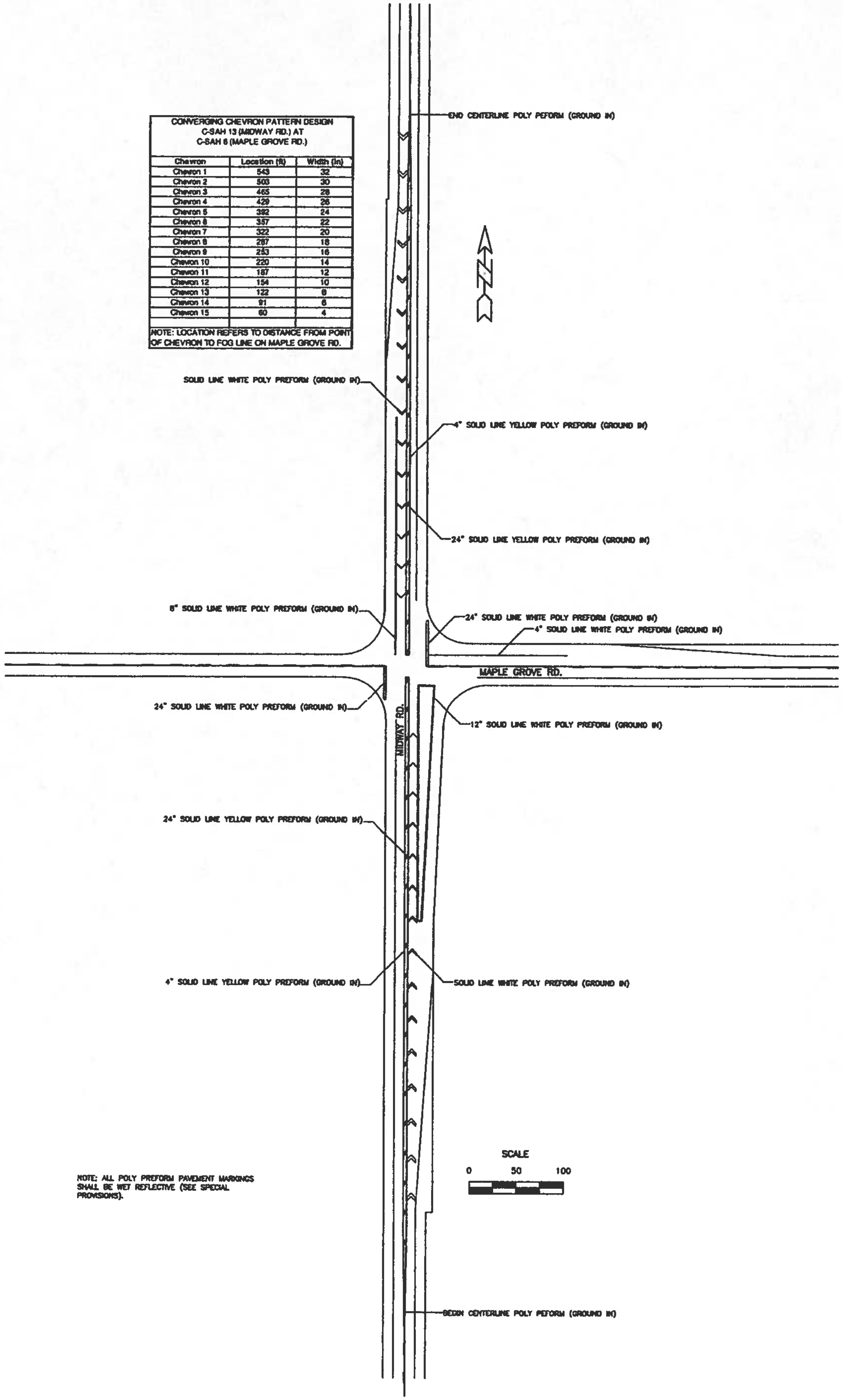
LOS = D

INTEGRATED SPEED REDUCTION TREATEMENT FOR INTERSECTIONS

"LAYOUT"

CONVERGING CHEVRON PATTERN DESIGN C-SAH 13 (MIDWAY RD.) AT C-SAH 6 (MAPLE GROVE RD.)		
Chevron	Location (ft)	Width (in)
Chevron 1	543	32
Chevron 2	503	30
Chevron 3	465	28
Chevron 4	429	26
Chevron 5	392	24
Chevron 6	357	22
Chevron 7	322	20
Chevron 8	287	18
Chevron 9	253	16
Chevron 10	220	14
Chevron 11	187	12
Chevron 12	154	10
Chevron 13	122	8
Chevron 14	91	6
Chevron 15	60	4

NOTE: LOCATION REFERS TO DISTANCE FROM POINT OF CHEVRON TO FOG LINE ON MAPLE GROVE RD.



NOTE: ALL POLY PREFORM PAVEMENT MARKINGS SHALL BE WET REFLECTIVE (SEE SPECIAL PROVISIONS).

Z:\Project Files\2011 OVERLAYS\midway_maple grove.dwg, 11/23/2010 2:51:42 PM

INTEGRATED SPEED REDUCTION TREATEMENT FOR INTERSECTIONS

“DESIGN CALCULATIONS”

Converging Chevron Pattern Design

v_o	55	mi/hr →	80.85	ft/sec
v_1	45	mi/hr →	66.15	ft/sec
a	-2.50	ft/sec^2		
t_r	0.5	sec		
Rate	2.2	chev/sec		
L	472.6	ft		
t_{total}	6.50	sec		
Chev #	15			
Spaces	14			

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

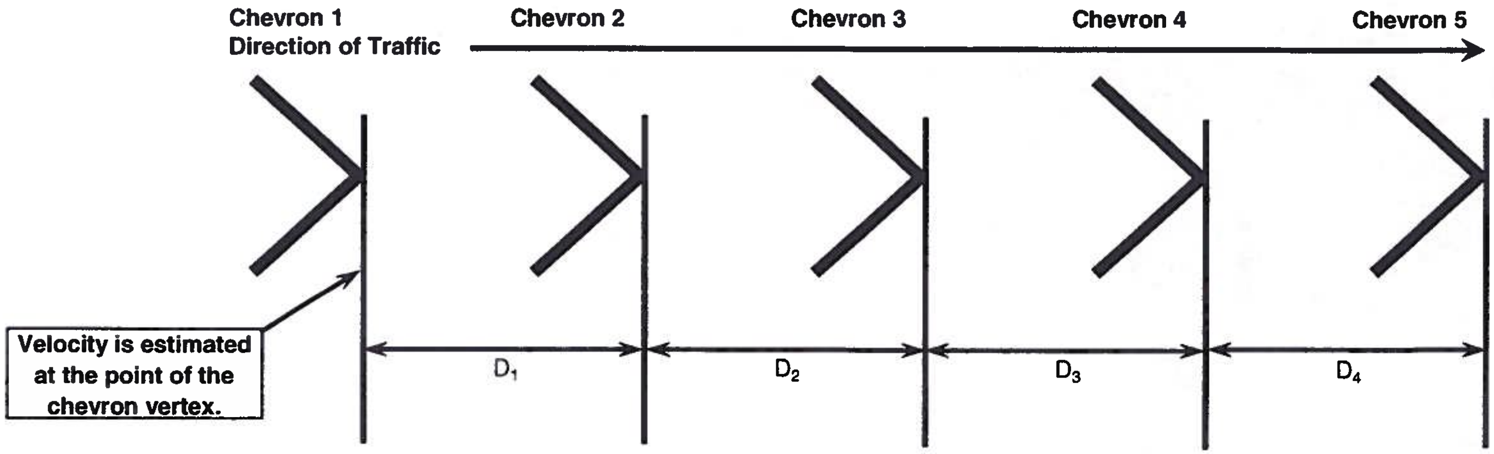
Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

Direction of Traffic ↓

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
Chevron 1	80.85	40.4	543	32
Chevron 2	80.85	37.3	503	30
Chevron 3	79.69	36.7	465	28
Chevron 4	78.53	36.2	429	26
Chevron 5	77.37	35.6	392	24
Chevron 6	76.21	35.1	357	22
Chevron 7	75.05	34.6	322	20
Chevron 8	73.89	34.0	287	18
Chevron 9	72.73	33.5	253	16
Chevron 10	71.57	32.9	220	14
Chevron 11	70.41	32.4	187	12
Chevron 12	69.25	31.9	154	10
Chevron 13	68.09	31.3	122	8
Chevron 14	66.92	30.8	91	6
Chevron 15	65.76	30.3	60	4
Intersection Offset			30	



V_1 = 80.85 ft/sec	V_2 = 80.85 ft/sec	V_3 = 79.69 ft/sec	V_4 = 78.53 ft/sec
D_1 = 40.4 ft	D_2 = 37.3 ft	D_3 = 36.7 ft	D_4 = 36.2 ft

It is assumed upon crossing the first chevron, a driver will only perceive the chevron pattern at this point. The time to travel distance D_1 is identified as the reaction time, t_r. It is assumed there will be no reduction in speed over this distance. Therefore D_1 is computed by $V_1 * t_r$ where V_1 is the speed before entering the chevron pattern.

Because there is assumed to be no speed reduction between Chevron 1 and Chevron 2, V_2 is equal to V_1. The distance, D_2 is calculated using the equation $d = v_o t + 1/2at^2$ where v_o is equal to V_2, a is the decleration constant and t is calculated by dividing the time to travel the distance of the total length of the chevron pattern, t_{total} by the total number of spaces in the chevron pattern. It is assumed a vehicle will experience uniform deceleration over the entire chevron pattern. The estimated velocity, V_3 at Chevron 3 is calculated using the equation $v_f = v_o + at$ where v_f is equal to V_3, v_o is equal to V_2, a is the deceleration constant and t is calculated the same as used in the equation for D_2. The remaining distance and velocity values of the chevron pattern are computed the same as D_2 and V_3.

Velocity Calculation

Microsoft Excel - Midway-Maple Grove Converging Chevron Design.xls

=IF(G5=0,0,H4+($B$3*($B$7/$B$9)))

v_o	55	mi/hr →	80.85	ft/sec
v_f	45	mi/hr →	66.15	ft/sec
a	-2.50	ft/sec²		
t_r	0.5	sec		
Rate	2.2	chev/sec		
L	472.6	ft		
t_{total}	6.50	sec		
Chev #	15			
Spaces	14			

Direction of Traffic

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
Chevron 1	80.85	40.4	543	32
Chevron 2	80.85	37.3	503	30
Chevron 3	79.69	36.7	465	28
Chevron 4	=IF(G5=0,0,H4+(	36.2	429	26
Chevron 5	77.37	35.6	392	24
Chevron 6	76.21	35.1	357	22
Chevron 7	75.05	34.6	322	20
Chevron 8	73.89	34.0	287	18
Chevron 9	72.73	33.5	253	16
Chevron 10	71.57	32.9	220	14
Chevron 11	70.41	32.4	187	12
Chevron 12	69.25	31.9	154	10
Chevron 13	68.09	31.3	122	8
Chevron 14	66.92	30.8	91	6
Chevron 15	65.76	30.3	60	4

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

Distance Calculation

Microsoft Excel - Midway-Maple Grove Converging Chevron Design.xls

File Edit View Insert Format Tools Data Window Help

SUM =IF(G5=0,0,(H5*($B$7/$B$9))+(0.5*$B$3*($B$7/$B$9)^2))

v_o	55	mi/hr →	80.85	ft/sec
v_f	45	mi/hr →	66.15	ft/sec
a	-2.50	ft/sec²		
t_r	0.5	sec		
Rate	2.2	chev/sec		
L	472.6	ft		
t_{total}	6.50	sec		
Chev #	15			
Spaces	14			

Direction of Traffic

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
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INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

Location Calculation

Microsoft Excel - Midway-Maple Grove Converging Chevron Design.xls

SUM =J6+I5

v_o	55	mi/hr →	80.85	ft/sec
v_f	45	mi/hr →	66.15	ft/sec
a	-2.50	ft/sec^2		
t_r	0.5	sec		
Rate	2.2	chev/sec		
L	472.6	ft		
t_{total}	6.50	sec		
Chev #	15			
Spaces	14			

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

Direction of Traffic ↓

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
Chevron 1	80.85	40.4	543	32
Chevron 2	80.85	37.3	503	30
Chevron 3	79.69	36.7	465	28
Chevron 4	78.53	36.2	=J6+I5	26
Chevron 5	77.37	35.6	392	24
Chevron 6	76.21	35.1	357	22
Chevron 7	75.05	34.6	322	20
Chevron 8	73.89	34.0	287	18
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Chevron 10	71.57	32.9	220	14
Chevron 11	70.41	32.4	187	12
Chevron 12	69.25	31.9	154	10
Chevron 13	68.09	31.3	122	8
Chevron 14	66.92	30.8	91	6
Chevron 15	65.76	30.3	60	4

Width Calculation

Microsoft Excel - Midway-Maple Grove Converging Chevron Design.xls

SUM f_x =K6+2

v_o	55 mi/hr →	80.85 ft/sec
v_f	45 mi/hr →	66.15 ft/sec
a	-2.50 ft/sec^2	
t_r	0.5 sec	
Rate	2.2 chev/sec	
L	472.6 ft	
t_{total}	6.50 sec	
Chev #	15	
Spaces	14	

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

Direction of Traffic ↓

Chevron	Velocity (ft/sec)	Distance (ft)	Location (ft)	Width (in)
Chevron 1	80.85	40.4	543	32
Chevron 2	80.85	37.3	503	30
Chevron 3	79.69	36.7	465	28
Chevron 4	78.53	36.2	429	=K6+2
Chevron 5	77.37	35.6	392	24
Chevron 6	76.21	35.1	357	22
Chevron 7	75.05	34.6	322	20
Chevron 8	73.89	34.0	287	18
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Chevron 13	68.09	31.3	122	8
Chevron 14	66.92	30.8	91	6
Chevron 15	65.76	30.3	60	4

	A	B	C	D	E
1	v_o				ec
2	v_f				ec
3	a				
4	t_r	0.5	sec		
5	*Rate*	2.2	chev/sec		
6	L	472.6	ft		
7	t_{total}	6.50	sec		
8	Chev #	15			
9	*Spaces*	14			

Velocity of vehicle immediately before entering the chevron pattern (initial velocity), ft/sec.

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E
1	v_o	55	mi/hr	80.85	ft/sec
2	v_f				ec
3	a				
4	t_r	0.5	sec		
5	*Rate*	2.2	chev/sec		
6	L	472.6	ft		
7	t_{total}	6.50	sec		
8	Chev #	15			
9	*Spaces*	14			

Velocity of vehicle immediately upon leaving the chevron pattern (final velocity), ft/sec.

<u>INSTRUCTIONS</u>

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E	F	G
1	v_o	55	mi/hr →	80.85	ft/sec		Chevro
2	v_f						Chevron
3	a						vron
4	t_r						vron
5	Rate						vron
6	L						vron
7	t_{total}						vron
8	Chev #						vron
9	Spaces	14					Chevron
10							Chevron
11							Chevron
12							Chevron
13							Chevron
14							Chevron
15							Chevron
16							Chevron
17							
18							
19							
20							
21							
22							
23							

Deceleration value of a vehicle slowing down through the chevron pattern.

Determined in the field by measuring the time for a passenger vehicle to decelerate by coasting from the initial velocity to the final velocity. I ran 10 coasting deceleration trials from 55 to 45 mph and found an average deceleration time of 12.3 seconds. From this time, the deceleration was calculated as -1.20 ft/sec^2.

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E
1	v_o	55	mi/hr →	80.85	ft/sec
2	v_f	45	mi/hr →	66.15	ft/sec
3	a	[illegible]	[illegible]		
4	t_r	[illegible]			
5	Rate	2.2	chev/sec		
6	L	472.6	ft		
7	t_{total}	6.50	sec		
8	Chev #	15			
9	Spaces	14			

Time for a driver to react to the chevron pattern.

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E	F
1	v_o	55	mi/hr →	80.85	ft/sec	
2	v_f	45	mi/hr →	66.15	ft/sec	
3	a	-2.50	ft/sec^2			
4	t_r	0.5	sec			
5	*Rate*					
6	L					
7	t_{total}					
8	Chev #					
9	*Spaces*					

The number of chevrons crossed by a vehicle per second. Assumed to be 2.2 chevrons/sec.

Drakopoulos A., Vergou. G. 2003. *Evaluation of the Converging Chevron Pavement* Marking Pattern at One Wisconsin Location. AAA Foundation for Traffic Safety.

<u>INSTRUCTIONS</u>

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E	F
1	v_o	55	mi/hr →	80.85	ft/sec	
2	v_f	45	mi/hr →	66.15	ft/sec	
3	a	-2.50	ft/sec^2			
4	t_r	0.5	sec			
5	*Rate*					
6	L					
7	t_{total}					
8	Chev #					
9	*Spaces*					

Direction of Traffic

L is determined by the following equation:

$$L = (v_o * t_r) + [(v_o^2 - v_r^2)/(2*a)]$$

Drakopoulos A., Vergou. G. 2003. *Evaluation of the Converging Chevron Pavement Marking Pattern at One Wisconsin Location*. AAA Foundation for Traffic Safety.

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E	F	G
1	v_o	55	mi/hr →	80.85	ft/sec		Chev
2	v_f	45	mi/hr →	66.15	ft/sec		Chevr
3	a	-2.50	ft/sec^2				Chevr
4	t_r	0.5	sec			Directio	Chevr
5	*Rate*	2.2	chev/sec				Chevr
6	L						
7	t_{total}						
8	Chev #						
9	*Spaces*						

Total time (t_{total}) for a vehicle to travel the total length of the chevron pattern. Determined by the following equation:

$$d = v_o t + 1/2 a t^2$$

Known variables: d (i.e. L), v_o and a. Solve for t.

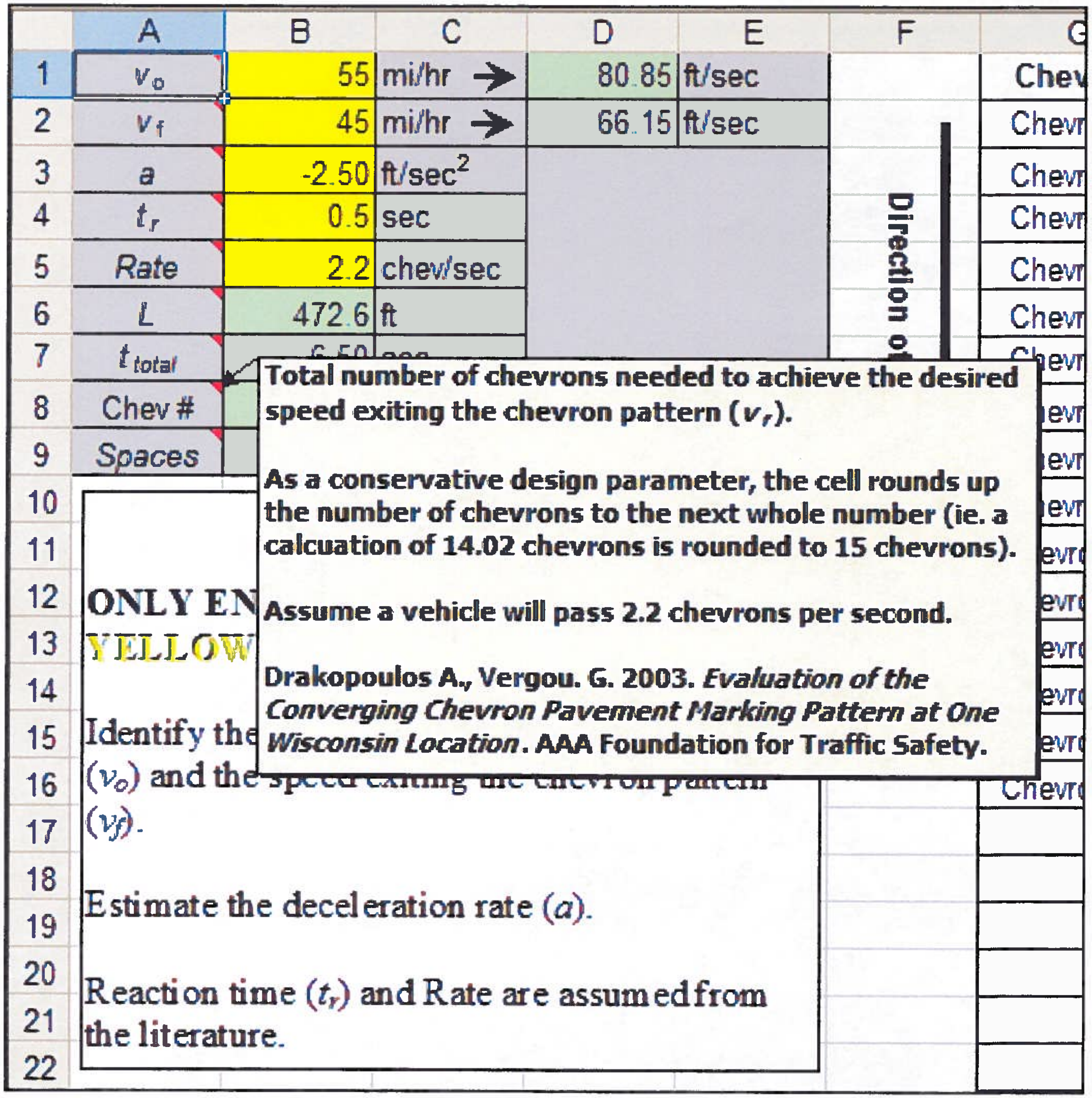
$$t = (\sqrt{(v_o^2) + (2ad)} - v_o)/a$$

ONLY EN... YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.



v_o 55 mi/hr → 80.85 ft/sec
v_f 45 mi/hr → 66.15 ft/sec
a -2.50 ft/sec^2
t_r 0.5 sec
Rate 2.2 chev/sec
L 472.6 ft
t_{total}
Chev #
Spaces
Direction of
Total number of chevrons needed to achieve the desired speed exiting the chevron pattern (v_f).
As a conservative design parameter, the cell rounds up the number of chevrons to the next whole number (ie. a calcuation of 14.02 chevrons is rounded to 15 chevrons).
Assume a vehicle will pass 2.2 chevrons per second.
Drakopoulos A., Vergou. G. 2003. *Evaluation of the Converging Chevron Pavement Marking Pattern at One Wisconsin Location*. AAA Foundation for Traffic Safety.
ONLY EN
YELLOW
Identify the
(v_o) and the
(v_f).
Estimate the deceleration rate (a).
Reaction time (t_r) and Rate are assumed from the literature.

	A	B	C	D	E
1	v_o	55	mi/hr →	80.85	ft/sec
2	v_f	45	mi/hr →	66.15	ft/sec
3	a	-2.50	ft/sec^2		
4	t_r	0.5	sec		
5	*Rate*	2.2	chev/sec		
6	L	472.6	ft		
7	t_{total}	6.50	sec		
8	Chev #	[illegible]			
9	*Spaces*				

Total number of spaces in the chevron pattern.

INSTRUCTIONS

ONLY ENTER VARIABLES INTO THE YELLOW CELLS.

Identify the speed entering the chevron pattern (v_o) and the speed exiting the chevron pattern (v_f).

Estimate the deceleration rate (a).

Reaction time (t_r) and Rate are assumed from the literature.

INTEGRATED SPEED REDUCTION TREATEMENT FOR INTERSECTIONS

"GAP TIME CALCULATIONS"

4:00 – 4:15 pm

VOLUME = 305 VEHICLES

V = FLOW RATE

D = DENSITY

AVERAGE SPEED, $S = 41$ mph

AVERAGE HEADWAY, $h_a = 2.94$ sec

$$V = S \cdot D$$

$$V = \frac{3{,}600}{h_a} = \frac{3{,}600}{2.94} = 1{,}224 \text{ veh/hr/ln}$$

$$D = V/S = \frac{1{,}224}{41} = 29.9 \text{ veh/mi/ln}$$

ASSUME TREATMENT REDUCES AVERAGE SPEED BY 5.0 mph. $S_2 = S_1 - 5 = 41 - 5 = 36$ mph

$$V = S \cdot D = (36)(29.9) = 1076 \text{ veh/hr/ln}$$

$$h_a = \frac{3{,}600}{V} = \frac{3{,}600}{1{,}076} = 3.35 \text{ sec}$$

$$\Delta = h_{a_2} - h_{a_1} = 3.35 - 2.94 = \boxed{0.41 \text{ sec}}$$

5:00-5:15 pm

VOLUME = 121 VEHICLES

AVERAGE SPEED, S = 44 mph

AVERAGE HEADWAY, h_a = 7.38 sec

V = FLOW RATE

D = DENSITY

$$V = S \cdot D$$

$$V = \frac{3{,}600}{h_a} = \frac{3{,}600}{7.38} = 487 \text{ veh/hr/ln}$$

$$D = V/S = \frac{487}{44} = 11.1 \text{ veh/mi/ln}$$

ASSUME TREATMENT REDUCES AVERAGE SPEED BY 5.0 mph. $S_2 = S_1 - 5 = 44 - 5 = 39$ mph

$$V = S_2 \cdot D = (39)(11.1) = 433 \text{ veh/hr/ln}$$

$$h_a = \frac{3{,}600}{V} = \frac{3{,}600}{433} = 8.31 \text{ sec}$$

$$\Delta = h_{a_2} - h_{a_1} = 8.31 - 7.38 = \boxed{0.93 \text{ sec}}$$

BENEFIT/COST ANALYSIS

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
	Various	Intersection of Midway Road and Maple Grove Road			St. Louis Co.	1/1/2000	12/31/2009

Description of Proposed Work: Implement lane narrowing and converging chevrons on both major approaches.

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			1						1
		B				2				1	3
		C	2		1	5					8
	Property Damage	PD	5	2		5	1	2		2	17
% Change in Crashes *Use Desktop Reference for Crash Reduction Factors	Fatal	F	54%			-42%					
	PI	A	54%			-42%					
		B	54%			-42%					
		C	54%			-42%					
	Property Damage	PD	54%			-42%					
Change in Crashes = No. of crashes X % change in crashes	Fatal	F									
	PI	A			0.00						
		B				-0.84				0.00	-0.84
		C	1.08		0.00	-2.10					-1.02
	Property Damage	PD	2.70	0.00		-2.10	0.00	0.00		0.00	0.60

Year (Safety Improvement Construction)	2011
Project Cost (exclude Right of Way)	$ 25,000
Right of Way Costs (optional)	
Traffic Growth Factor	2%
Capital Recovery	
1. Discount Rate	4.5%
2. Project Service Life (n)	10

Type of Crash	Study Period: Change in Crashes	Annual Change in Crashes	Cost per Crash	Annual Benefit
F			$ 780,000	
A			$ 390,000	
B	-0.84	-0.08	$ 121,000	$ 10,158
C	-1.02	-0.10	$ 75,000	$ 7,646
PD	0.60	0.06	$ 12,000	$ (720)
Total				$ 17,085

B/C= 6.14

Using present worth values.

B= $ 153,579

C= $ 25,000

See "Calculations" sheet for amortization.

Office of Traffic, Safety and Technology December 2008

Amortizing...

Year	Crash Benefits	Present Worth Benefits	Present Worth Costs
2011	$ 17,085	$ 17,085	$ 25,000
2012	$ 17,426	$ 16,676	
2013	$ 17,775	$ 16,277	
2014	$ 18,130	$ 15,888	
2015	$ 18,493	$ 15,507	
2016	$ 18,863	$ 15,136	
2017	$ 19,240	$ 14,774	
2018	$ 19,625	$ 14,421	
2019	$ 20,017	$ 14,076	
2020	$ 20,418	$ 13,739	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
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0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
0	$ -	$ -	
	Totals =	**$ 153,579 (B)**	**$ 25,000 (C)**

year (n)= 1, 2, 3,....
discount rate (i) = 7%

Crash Benefits (@ year n) = $(\text{Crash Benefits})_{n-1}$ X (1 + Traffic Growth Factor)

Present Worth Benefits (@ year n) = $(\text{Crash Benefits})_{n}$ X $1/(1 + \text{Discount Rate})^{n}$