MnDOT Trunk Highway 5: Jamaica Avenue to Manning Avenue/CSAH 15

Road Safety Audit Review
Technical Report

February 13, 2013
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Introduction

MnDOT, Washington County and Lake Elmo have and continue to work collaboratively to address safety concerns along Minnesota Trunk Highway (MNTH) 5 through the City of Lake Elmo. As a result of this collaboration, several roadway safety improvements have been implemented, such as the Jamaca Avenue roundabout, the addition of edge line rumble strips and left turn lanes on highways east of County State Aid Highway (CSAH) 15. However, Lake Elmo residents, businesses, school interests and elected officials continue to be concerned about safety and speeds along Hwy 5. A crash in August 2012 that resulted in severe injuries to two young city residents has also focused attention on the community’s safety concerns. MnDOT, Washington County and the city decided to assemble a team of safety professionals to conduct a Road Safety Audit of the segments of MNTH 5 between Jamaca Avenue and Manning Avenue/CSAH 15 (Figure 1) to take a new look at the corridor and make recommendations as to other actions that could be considered to further improve the roadway. This report discusses the process, data reviewed and recommendations of the Road Safety Audit Review Team.

Figure 1

MNTH 5 RSAR Study Area
**Road Safety Audit Review (RSAR) Team**

MnDOT assembled an independent team of safety experts representing MnDOT, the Federal Highway Administration, the Minnesota State Patrol and the private sector. Table 1 lists the members of the Road Safety Audit team that went out to the corridor during the review process and the support staff that met with the review team to provide insight into the history of the corridor and current conditions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Agency</th>
<th>Name</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brad Estochen</td>
<td>MnDOT State Safety Engineer</td>
<td>Adam Josephson</td>
<td>MnDOT Metro Area Manager</td>
</tr>
<tr>
<td>Derek Leuer</td>
<td>MnDOT Safety Engineer</td>
<td>Chad Erickson</td>
<td>MnDOT Metro Traffic</td>
</tr>
<tr>
<td>Darwin Yasis</td>
<td>MnDOT Geometrics</td>
<td>Wayne Sandberg</td>
<td>Washington County Engineer</td>
</tr>
<tr>
<td>Rog Ege</td>
<td>MnDOT District 1-Duluth Traffic</td>
<td>Joe Gustafson</td>
<td>Washington County Transportation Engineer</td>
</tr>
<tr>
<td>Gina Mitteco</td>
<td>Metro Pedestrian/Bicycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Will Stein</td>
<td>Federal Highway Administration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bjorn Erickson</td>
<td>Washington County Sheriff’s Office</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Howard Preston</td>
<td>CH2M HILL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nikki Farrington</td>
<td>CH2M HILL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Road Safety Audit Review Process**

The MNTH 5 Road Safety Audit Review process included the following steps:

1. Crash data from 2002 to 2011 were assembled using the Minnesota Crash Mapping Analysis Tool (MnCMAT) and analyzed for location, frequency, type, severity, time of day, light conditions, weather conditions and road conditions.
2. Traffic volumes for the corridor were documented.
3. Two meetings were held, one with the Lake Elmo City Council, elected officials, local law enforcement and Lake Elmo residents, and one follow-up meeting with MnDOT Metro District and Washington County staff.
4. After the meetings, the team examined the corridor and intersections in the field, recorded observations and suggestions and discussed possible mitigation strategies.

**Lake Elmo City Council Meeting**

The team participated in a meeting at the Lake Elmo City Hall on December 17, 2012, the day prior to the Road Safety Audit Review with the MNTH 5 RSAR review team. In attendance were elected local officials, law enforcement, business representatives, school interests and area residents. Participants
shared their concerns and observations about the highway. Main topics of discussion during the meeting included:

- Speed of vehicles on MNTH 5
- Difficulty for pedestrians trying to cross MNTH 5, especially school children from the adjacent Lake Elmo Elementary School, and the bad placement of the existing crosswalk
- Delays at intersections during the peak hours
- Danger of intersections due to their skewed angles

**RSAR Team Meeting**
The RSAR team met the morning of December 18, 2012 prior to a field review of the corridor with MnDOT Metro District and Washington County staff regarding the Audit. Many of the discussion topics reiterated those from the Lake Elmo City Hall Meeting and included:

- Types of crashes along the corridor
- Intersection crash statistics
- Traffic Volumes
- Speed
- Pedestrian accommodations

**Background**

**Corridor History**
MNTH 5 is a major east-west corridor for the northeast metro area providing a connection between Interstate 694 to locations to the east including the Cities of Lake Elmo and Stillwater. The current functional classification of the roadway is an A Minor Expander. The audit area is a 2-lane roadway with turn lanes and bypass lanes at some of the public street access locations. The corridor includes adjacent land uses that represent a primarily rural location with field and residential access only. A half mile section that goes through the downtown area of Lake Elmo includes multiple local street and private accesses and commercial/institutional adjacent land uses.

The MNTH 5 corridor is an important corridor because of the limited east-west connections within the region that provide connections to Interstate 694. The nearest parallel east-west roadways is MNTH 36, over 2 ½ miles to the north of MNTH 5 and County Highway 10, located almost 2 ½ miles to the south as shown in Figure 3. Natural features, such as the lakes north and south of MNTH 5, create barriers for any future east-west connections in the area, increasing the importance of the MNTH 5 corridor.
Implemented Safety Projects
MnDOT has implemented a number of safety improvements along the MNTH 5 corridor in recent years, including:

- 2003 – MNTH 5 between Manning Avenue to 58th Street Speed limit changed from 55 to 50 mph. 
  Note: There was no change in driver speeds (85th Percentile Speeds remained the same for both before and after scenarios)
- 2009 - Conversion to 3-lane east of Manning Avenue/CH 15
- 2010 - Installation of Roundabout at Jamaca Avenue/CH 6

Programmed Improvement Projects
There is a resurfacing improvement project currently funded for MNTH 5 in the study area. MnDOT plans to complete the project in 2013.

Figure 3
Regional East-West Roadways

Crash Characteristics
Crash data were gathered for the ten year period from 2002 to 2011 using the Minnesota Crash Mapping and Analysis Tool (MnCMAT). A ten year study period for data was selected because a sufficient number of crashes were included in the data set to provide credible results. The 2002 to 2011 time frame was used because 2011 is the most recent year of crash data included in MnCMAT. The crash analysis consisted of disaggregating the crashes by segment and intersection and then documenting the number of crashes, the severity of crashes, the types of crashes, computing crash rates which account for exposure (traffic volume) and then comparing the results to statewide averages for similar segments and intersections.
Segments

For the purposes of this analysis, the MNTH 5 corridor was divided into three segments. The West and East segments are classified as Rural 2-Lane highways and the Middle Segment is classified as an Urban 2-Lane highway. A Critical Crash Rate is a statistical baseline used to compare crash experience of a segment against its peers. When a Crash Rate for a segment exceeds the Critical crash rate, we know this is due to some environmental or roadway characteristic. This tool is used to help identify roadway segments that require further investigation. Three crash rates were considered:

1. Crash Rate – the crash rate includes all crashes for a segment including fatal crashes, severe crashes (a crash that causes an injury preventing an individual from doing activities they were capable of before the crash), moderate crashes (injury that was evident at the scene of the crash), minor injury (no evident injury at the crash scene, but individual complaining of possible injury), and property damage crashes where there are no injuries. Crash Rates are based on the number of crashes per million vehicle miles.

2. Severity Rate – this rate is calculated using a weighted average for all crashes with the highest weight for fatal crashes and the lowest weight for property damage. Severity Crash Rates are also based on the number of crashes per million vehicle miles.

3. Fatality Rate – this rate uses only fatal crashes and is based on an exposure of a hundred million vehicle miles.

The results of the segment crash analysis are documented in Table 2 and show that the Middle and the East segment both had crash rates higher than the critical crash rate (shown in bold text in Table 2) suggesting these two segments may benefit from safety improvements. The key points for each segment are included in the following sections.

Table 2

| Segment Crash Summary |
|------------------------|-----------------|-----------------|
|                        | **West Segment** | **Middle Segment** | **East Segment** |
| # of Crashes (2002-2011) | 50              | 74              | 72              |
| Severity of Crashes    |                 |                 |                 |
| 1 Fatal crash          |                 | No fatal crashes | No fatal crashes |
| 1 serious injury        |                 | 1 serious injury | No serious injury |
| 11 moderate/minor injury |               | 20 moderate/minor injury | 25 moderate/minor injury |
| 37 property damage      |                 | 53 property damage | 47 property damage |
| Type of Crashes        | Mix of crash types | Majority rear and right angle crashes | Majority rear end crashes |
| Crash Rate/Critical Crash Rate | 0.6 / 1.1 | **3.4** / **3.1** | **2.1** / **1.2** |
| Severity Rate/Critical Severity Rate | 0.9 / 1.6 | **4.9** / **4.3** | **3.0** / **1.5** |
| Fatality Rate/Critical Fatality Rate | 1.2 / 3.4 | 0 / 6.5 | 0 / 4.8 |
**West Segment (Jamaca Ave to CSAH17 – (west))**

- During the study period, there were 50 crashes. Of those crashes one (2% of all crashes) was fatal, one (2% of all crashes) was a serious injury crash, 11 (22% of all crashes) were moderate or minor injury crashes and 37 (74% of all crashes) were property damage only crashes.
- Figure 4 shows a comparison of the crash types that occurred in the West Segment against peer segments throughout the state. There was a higher percentage of rear-end crashes in the West Segment. The percentages for right angle crashes and sideswipe opposing crashes were less than the expected amount on the West Segment compared to its peer segments.
- The Crash Rate of 0.6 does not exceed the baseline Critical Crash rate of 1.1, which indicates that there are fewer crashes compared to peer roadways. In addition, both the Severity Rate of 0.9 and Fatality Rate of 1.2 are less than the critical rates.

**Middle Segment (CH 17 (west) – 39th St)**

- In the Middle Segment there were 74 crashes during the study period. There were no fatal crashes, but one serious injury crash (1% of all crashes). In addition, there were 20 moderate or minor injury crashes (27% of all crashes) and 53 (72% of all crashes) property damage only crashes.
- As in the West Segment, the distribution of crash types was compared to the statewide average distribution for a similar roadway. This distribution for the Middle Segment is shown in Figure 5. For this segment, there were more rear end and right angle crashes than would be expected compared to peer roadways.
- The Crash Rate of 3.4 does exceed the baseline Critical Crash rate of 3.1 and the Severity Crash Rate of 4.9 also exceeds the critical rate of 4.3, indicating that there are more crashes than would be
expected when compared to peer roadways. There were no fatal crashes, so the Fatality Crash Rate is zero.

**East Segment (39th St - Manning (CR15))**

- Of the 72 crashes in the East Segment during the study period, there were no fatal or serious injury crashes. The crashes for this segment were either moderate/minor crashes (35% of the crashes) or property damage (65% of the crashes).
- The actual Crash Rate of 2.1 is greater than the Critical Crash Rate which is 1.2 and the Severity Crash Rate of 3.0 is also greater the critical rate of 1.5. However, it should be noted that this is based entirely on the occurrence of minor injury crashes – the segment experienced no fatal or serious injury crashes during the study period.
- As in the other segments, the distribution of crash types was compared to the statewide average distribution for a similar roadway. This distribution for the East Segment is shown in Figure 6. For this segment, there were more rear end crashes than would be expected compared to peer roadways.
Intersections
Using MnCMAT, crash overviews were developed for each of the fourteen intersections in the MNTH 5 study area. While intersection crashes were analyzed separately, intersection crashes were included in the segment analyses presented above. Over 90% of the crashes along the MNTH 5 corridor were intersection related. The findings of the intersection crash analysis are documented in Table 3, including the intersection configuration (T indicating a three-leg “T” intersection, Y represents at “T” intersection with skewed approaches, X representing a four-legged intersection and O indicating a roundabout) and a summary of the crashes and crash rates. The key points include:

- The intersection of MNTH 5/Jamaca Avenue had the highest Crash Rate (0.7) over the ten-year analysis period. However, following construction of the roundabout in 2010 the Crash Rate dropped by more than 40%.
- The intersection of MNTH 5/Manning Avenue had the highest frequency of crashes, which averaged to slightly more than 4 crashes per year, however, the Crash Rate of 0.6 is less than the Critical Rate of 0.8.
- Nine of the remaining intersections with MNTH 5 (31st Street, Stillwater Lane West, Kelvin Avenue, Stillwater Lane East, Klondike Avenue, Laverne Avenue, Layton Avenue, 39th Street, and Little Bluestem Trail) average approximately one or fewer crashes per year and the Crash Rates at each intersections is less than the critical crash rate.
- The two intersections with CSAH 17 (Lake Elmo Avenue) average between 2 and 3 crashes per year which results in an actual Crash Rate of approximately 0.5, which is greater than the statewide average for similar (STOP controlled) intersections and exceeds than the Critical Crash Rate.

Pedestrian and Bicycle Crash Summary
There was one reported pedestrian/bicycle crash on the corridor in last ten years; a minor injury crash involving a bicyclist at the MNTH 5 signal at Manning Avenue in 2004.

Current research, as part of the statewide County Road Safety Plans, has provided the following insights:
- In the metro area, almost 70% of pedestrian and bike crashes occur at intersections
- Of these intersection crashes, almost 60% are at signalized intersections
- A majority of these crashes occur on corridors at 40 mph or less

There was discussion at the Lake Elmo City Hall meeting about the Lake Elmo Elementary School’s desire to cross MNTH 5 with classes to visit other sites within the city. It was shared at the meeting that due to a few “close calls” of vehicles almost hitting adults assisting in the activity, they chose to limit the elementary students’ school activities involving using the crosswalk. Additional or modified pedestrian accommodations near the school were requested.
Table 3

Intersection Crash Summary

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total Crashes</th>
<th>Severe Crashes (K&amp;A)</th>
<th>Observed Crash Rate</th>
<th>Critical Crash Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Segment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jamaca Avenue X (2002-2009) O (2011)</td>
<td>28</td>
<td>0</td>
<td>0.7</td>
<td>0.5</td>
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<tr>
<td>31st St/MSAS 109 T</td>
<td>10</td>
<td>1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Stillwater Lane (West) X</td>
<td>7</td>
<td>0</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Kelvin Avenue T</td>
<td>9</td>
<td>0</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Stillwater Lane (East) T</td>
<td>5</td>
<td>0</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Klondike Avenue T</td>
<td>9</td>
<td>0</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Middle Segment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH 17 (West) Y</td>
<td>28</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>CH 17 (East) Y</td>
<td>23</td>
<td>0</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Laverne Avenue X</td>
<td>15</td>
<td>0</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Layton Avenue Y</td>
<td>10</td>
<td>0</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>39th St/MSAS 114 T</td>
<td>6</td>
<td>0</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>East Segment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cemetery Drive T</td>
<td>1</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Little Bluestem Trail T</td>
<td>8</td>
<td>0</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Manning Ave/CR 14 (Signalized) T</td>
<td>42</td>
<td>0</td>
<td>0.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

203 2

NOTES:

**Bold** Crash Rates exceed the Critical Crash Rate
Crash Data from MnCMAT, 2002-2011
Expected Crash Data from MnCMAT, 2002-2011, 2-lane undivided intersections
Expected Crash Rates from MnDOT Crash Data Toolkit 2011 (Statewide system average)
*Roundabout critical rate based on small sample of roundabouts in Minnesota

**Traffic Volume Characteristics**

Historic traffic volume information for MNTH 5 was obtained from MnDOT volume maps from 1998 through 2010 as shown in Table 4. Existing traffic volumes along the corridor average almost 12,000 vehicles per day. There has been little change to the traffic volumes in the last twelve years with volumes ranging between 11,400 and 13,000 vehicles per day. The forecast for the year 2029 from Metropolitan Council’s Regional Travel Demand Model is 16,000 vehicles per day on this portion of MNTH 5.
Table 4

<table>
<thead>
<tr>
<th>Year</th>
<th>West Segment</th>
<th>Middle Segment</th>
<th>East Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>12,000</td>
<td>11,400</td>
<td>11,400</td>
</tr>
<tr>
<td>2000</td>
<td>12,000</td>
<td>11,900</td>
<td>11,900</td>
</tr>
<tr>
<td>2002</td>
<td>13,000</td>
<td>12,500</td>
<td>12,500</td>
</tr>
<tr>
<td>2004</td>
<td>12,700</td>
<td>13,000</td>
<td>13,000</td>
</tr>
<tr>
<td>2006</td>
<td>12,000</td>
<td>11,500</td>
<td>11,500</td>
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<tr>
<td>2008</td>
<td>12,500</td>
<td>11,800</td>
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</tr>
<tr>
<td>2010</td>
<td>11,700</td>
<td>11,500</td>
<td>11,500</td>
</tr>
<tr>
<td>2029 Forecast</td>
<td>16,000</td>
<td>16,000</td>
<td>16,000</td>
</tr>
</tbody>
</table>

Vehicle Speed Characteristics

The location of MNTH 5 through the downtown area of Lake Elmo has raised the question of the speed limits and the appropriate speeds of vehicles through this area. MnDOT performed a speed study along the corridor in August, 2012 to document speed profiles. A summary of the results of this speed study are shown in Table 5. The 85th percentile speed is the speed up to which 85 percent of vehicles were traveling. The 85th percentile speed is the primary performance measure for determining recommended speed limits. The 10 mph pace is 10 mph range in which the highest percent of the vehicles are going.

The study found the 85th percentile speed through all of the segments of the corridor were consistent with the current posted speed limits of 55 mph for the west segment, 40 mph for the middle segment and 50 mph for the east segment with the 85th percentile speeds within 5 mph of the posted limit.

Table 5

<table>
<thead>
<tr>
<th></th>
<th>West Segment</th>
<th>Middle Segment</th>
<th>East Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Posted Speed Limit</td>
<td>55 mph</td>
<td>40 mph</td>
<td>50 mph</td>
</tr>
<tr>
<td>85th Percentile Speed - EB</td>
<td>59</td>
<td>42</td>
<td>53</td>
</tr>
<tr>
<td>85th Percentile Speed - WB</td>
<td>57</td>
<td>43</td>
<td>52</td>
</tr>
<tr>
<td>10 mph Pace - EB</td>
<td>51-60</td>
<td>35-44</td>
<td>45-54</td>
</tr>
<tr>
<td>10 mph Pace - WB</td>
<td>51-60</td>
<td>37-46</td>
<td>44-53</td>
</tr>
<tr>
<td>% of traffic in 10 mph Pace - EB</td>
<td>88.6</td>
<td>92.3</td>
<td>93.0</td>
</tr>
<tr>
<td>% of traffic in 10 mph Pace - WB</td>
<td>94.7</td>
<td>87.7</td>
<td>88.4</td>
</tr>
</tbody>
</table>
Access Characteristics

A review of the access points along the three segments of MNTH 5 are provided in Table 6. The west segment has a high number of private access points; the middle segment has commercial accesses and the east segment several private access points. The east and west segments each averaged 12 to 13 access per mile. The middle segment, the ½ mile of MNTH 5 through the downtown area of Lake Elmo, has 20 accesses. Ten of the twenty accesses along the middle segment are for commercial and/or school land uses.

**Table 6**

Summary of MNTH 5 Access Characteristics

<table>
<thead>
<tr>
<th></th>
<th>West Segment</th>
<th>Middle Segment</th>
<th>East Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Access</td>
<td>15</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Commercial/Education Access</td>
<td>0</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Public Road Access</td>
<td>6</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Segment Length</td>
<td>1.8 miles</td>
<td>0.5 miles</td>
<td>0.6 miles</td>
</tr>
<tr>
<td>Access/Mile</td>
<td>12 access/mile</td>
<td>40 access/mile</td>
<td>13 access/mile</td>
</tr>
</tbody>
</table>

MnDOT has conducted detailed analysis of the relationship between access and safety on Minnesota’s Trunk Highway System. As shown in Figure 7, there is a statistical relationship between access density and crash rate with segments with higher access densities having higher crash rates in urban and rural areas. As part of the safety analysis of the corridor, a comparison of the access density to other similar roadways and the statewide average will provide insight into the need for access management along the corridor.

**Figure 7**

Relationship of Access Density and Crash Rates

Note: “Rural” Refers to a non-municipal area and cities with a population less than 5,000.

Field Review Observations
The RSA Team conducted a field review of the corridor on December 18th, 2012. The field review times included the morning travel peak, the morning arrival at the Elementary school, mid-day, the afternoon departure from the school and the afternoon travel peak. The key observations are documented in the following paragraphs.

Segments
- In the West and East segments the appearance of the road with ditches and wide paved shoulders supports driver’s perceptions of a rural environment and results in higher operating speeds.
- There are high levels of both public and private access in all segments.
- The Middle segment offers few visual cues to indicate an urban area, which drivers associate with lower speed roadways. For example, the roadway cross-section includes ditches as opposed to an urban section with curb and gutter. In addition, there no roadside indicators, such as sidewalks, boulevards, trees, street lights or street furniture, to provide an urban feel.

Intersections
- There are four intersections with skewed minor road approaches. Skewed intersections are known to contribute to safety concerns.
- None of the intersections had overhead street lighting, a common safety strategy for intersections.
- There are no designated left-turn lanes at the intersections which may account for the higher than average number of rear end crashes along the segment.
- During the peak hours, there were minor queues, particularly at the CSAH 17 intersections, but delays were short and queues dissipated in a reasonable amount of time.
- Intersection designs were not consistent throughout the corridor, with combinations of bypass lanes and some right turn lanes. This inconsistency may increase driver confusion as to the appropriate use of the right turn lanes (using them inappropriately as bypass lanes due to other adjacent bypass lanes).

School Operations
- Arrival and departure traffic for the Lake Elmo Elementary School is focused in the rear of the school. Having parent/student drop off in the back and only buses in the front adjacent to MNTH 5 seems to work well. There were only minor impacts to MNTH 5 traffic with some buses queuing onto the MNTH 5 shoulder (see Figure 7).

Figure 7
Crosswalk Location and Bus Queuing onto MNTH 5 Shoulder
• The existing crosswalk does not appear to be very effective. At its current location, the crosswalk does not connect to a trail system or sidewalks except a short trail that provides a circuitous connection to downtown. Additionally, the trail is located towards the end of the CSAH 17 bypass lane which creates a double threat risk to pedestrians by vehicles that utilize the bypass lane when a second vehicle is stopped for pedestrian.

Pedestrian Accommodations
There are no pedestrian accommodations along the MNTH5 roadway such as sidewalks or trails. The only marked crosswalk is near the CSAH 17 (west) intersection.

Street Network
The street network to support MNTH 5 is significantly under-developed as shown in Figure 3. There are no supporting east-west collectors or minor arterials due to lakes and existing residential subdivisions. As a result, east-west through traffic is concentrated on MNTH5 which adversely affects both traffic safety and operations. Also, there is shortage of north-south collector streets and minor arterials with no other north-south roadways except for county highways. As traffic volumes increase on MNTH 5 residents will likely have even greater challenges when trying to enter MNTH 5. The most requested improvement, adding a traffic signal, would not likely meet MnDOT thresholds because of low volumes on the minor street, as defined in the guidelines for traffic signals in the Minnesota Manual on Uniform Traffic Control Devices.

Potential Improvement Strategies

Segments
The following segment strategies were considered for mitigation of operational and safety issues on the MNTH 5 corridor. Strategies include:

• Safety & Operations – Three-Lane Segment
• Safety & Operations – 2+1 Segment
• Safety – Four-foot Buffer
• Safety – Twelve-foot Buffer
• Safety – Centerline Rumble Strips
• Speed Reduction – Reduce Speed Limit
• Speed Reduction – Dynamic Speed Sign
• Speed Reduction – School Speed Limit Zone
• Speed Reduction – Urban Configuration
• Pedestrian Accommodations
• Operations – Intersection Traffic Control
• Access Management
• Street Network

Three-Lane Segment
A traditional operational performance measure for roadways is the level of service (LOS). A letter, A through F, is assigned to a roadway or intersection based on performance, with A being the best (no congestion) and F being the worst (unacceptable congestion). MnDOT has not formally adopted performance measures for operations of 2-lane rural roadways. However, a mid level of service C has been used in some studies since it represents a condition with moderate levels of congestion during peak traffic periods, but with little or no congestion during the remainder of the day.
Without improvements the level of congestion on this segment is expected to increase. Using the current daily traffic volumes, capacity assumptions and peak hour percentages, the existing roadway is likely operating at level of service C as shown by the blue line in Figure 8 and looking at the 2-lane column. During peak hours, the existing roadway operates at a level of service D. In the future (shown as the red line in Figure 8) that the roadway will likely operate in the level of service E/F range, which would be considered poor roadway operations, if it remains a 2-lane cross-section.

However, if the highway is converted to 3-lane roadway it would operate near the level of service C/D boundary under future traffic forecasts (see red line and 3-lane roadway column in Figure 8). Figures 9 and 10 provide examples of both a rural and urban implementation of a 3-lane roadway. In addition the traffic operation benefits of a 3-lane roadway, there are safety benefits of this type of roadway configuration. A 3-lane roadway, that includes the introduction of left turn lanes, is considered a mitigation strategy for rear end crashes. All three segments experienced a higher than expected amount of rear end crashes in the last ten years and would benefit from this type of improvement. Also, the three-lane configuration has a lower expected crash rate of 2.5 crashes per million vehicle miles traveled, which is below the current crash rate of 3.4 for the middle segment.
Figure 8
Estimated Level of Service (LOS) Based on Average Daily Traffic Volumes

Note: This figure contains approximate values. The values are highly dependent on the assumptions used. It should not be used for operational analyses or final design.
Figure 9
Example 3-lane Rural Segment

Figure 10
Example 3-lane Urban Segment
2+1 Roadway

This strategy places 2 full lanes in one direction and 1 in the other with a median separation of 4-feet in which cable barrier can be placed to prevent vehicles from crossing over to oncoming lanes (Figure 11). This layout allows vehicles to pass throughout the corridor as the direction of the 2+1 alternates between travel directions, typically at one to two mile intervals. This technique has been used in Europe and has been found to virtually eliminate head on crashes since it restricts passing to the 2-lane sections and adds cable barrier to prevent crossover vehicles. The Crash Modification Factors (CMF) Clearinghouse, which determines the long-term expected reduction in crashes based on study sites, does not have a CMF for a 2+1 Road technique at this time. This type of strategy could be considered for the west segment but would also require some access management in order to implement the cable barrier.

Four-Foot Buffer

This technique involves widening the roadway in order to create a four-foot wide buffer area (with rumble strips) between the opposing lanes (Figure 12). This technique does not provide a physical barrier to separate the lanes; it merely provides some additional space so that an errant vehicle has some room to recover before entering the opposing lane.

This strategy has been tried in a number of places, including the USTH 12 bypass of Long Lake; however, no crash reduction factor has been developed. It should be noted that in the five years since USTH 12 was constructed, there has only been 1 head on crash, likely due to driver confusion caused by the adjacent railroad that gave the roadway the appearance of a 4-
lane divided roadway. This type of strategy could be considered for both the west and east segments but would require reconstructing and potentially widening the shoulders.

**12-foot Buffer**
This technique involves widening the existing roadway in order to create a twelve-foot wide buffer between the opposing lanes. As with the previous technique, there is no barrier to prevent errant vehicles from entering the opposing lane, the buffer merely provides a recovery space (Figure 13). In areas with no intersections, the center twelve feet is marked out with paint and in the vicinity of intersections, the markings transition into left turn lanes.

This strategy addresses head on crashes two ways; first by providing the buffer and second by prohibiting passing maneuvers. This twelve-foot buffer with painted left turn lanes has been tried in a number of places, including along MNTH 5 east of Manning Avenue. No crash reduction factor has been developed; however, the project east of Manning resulted in a 100% reduction in head on crashes and a 56% reduction in rear end and sideswipe crashes.

Implementation of this strategy could involve either total reconstruction of the roadway or reconstruction of the shoulders in addition to an overlay of the existing pavement with a reallocation of the entire pavement width by narrowing of both the lanes and shoulders to minimize cost and impacts.

**Centerline Rumble Strips**
This strategy involves adding a rumble strip on or near the centerline of the roadway to mitigate head-on and opposite direction sideswipe crashes. A rumble strip is installed adjacent to the center line and a rumble strip is when the yellow center line is painted over the grooves. A rumble strip allows for better retroreflectivity during wet conditions, as a vehicle’s head lights will be reflected by the glass beads in the paint on the sides of the grooves. Center line rumbles are installed as a countermeasure for driver error primarily to assist distracted, drowsy or otherwise inattentive drivers who unintentionally stray over the center line. They have been shown to have significant reductions in severe crashes from 38 to 50 percent on rural two-lane roadways and 37 to 91 percent reduction on urban two-lane roads (Source: NCHRP Report 641).
Reduce Speed Limit
Studies have shown that merely changing a speed limit sign is not successful in changing driver behavior and it has never resulted in a significant change in vehicle operating speeds. As shown in Table 6, various locations within Minnesota have attempted to change operating speeds along a corridor by changing the Speed Limit signs without impact.

Added speed enforcement efforts can be effective, but the effort has to be sustained, or speeds will typically resort to previous levels once enforcement subsides. The City of Lake Elmo contracted with the Washington County Sheriff’s office for increased enforcement with some success: however, officials confirmed that they are not likely to have sufficient staff to support the necessary level of effort for a long period of time. The most cost-effective method to having a 24/7 presence over an extended period of time involves using electronic surveillance—speed cameras.

Table 6
Before and After 85% Speeds Based on Speed Limit Sign Change

<table>
<thead>
<tr>
<th>Study Location</th>
<th>Old Speed Limit</th>
<th>New Speed Limit</th>
<th>Sign Change +/- MPH</th>
<th>85% Before/After</th>
<th>Change MPH</th>
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<tr>
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<td>55</td>
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<td>-5</td>
<td>58/59</td>
<td>+1</td>
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<tr>
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<td>40</td>
<td>30</td>
<td>-10</td>
<td>34/34</td>
<td>0</td>
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<tr>
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<td>50</td>
<td>40</td>
<td>-10</td>
<td>44/45</td>
<td>+1</td>
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<td>40</td>
<td>-5</td>
<td>48/50</td>
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<td>+5</td>
<td>39/40</td>
<td>+1</td>
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</table>

Source: Unpublished MnDOT data
**WB Dynamic Speed Feedback Sign (east segment)**

Dynamic speed feedback signs are placed at existing speed limit signs and providing the approaching vehicles speeds, often with blinking lights if they are above the posted speed limit. An example is shown in Figure 14. Eastbound MNTH 5 currently has a Dynamic Speed Feedback Sign installed, but the westbound direction does not have a sign at the transition from 50 mph to 40 mph. FHWA summarized ten different speed studies that documented the effectiveness of speed feedback signs (FHWA’s Engineering Countermeasures for Reducing Speeds: A Desktop Reference for Potential Effectiveness, May 2009). The reduction in the 85th percentile speeds varied, with most locations having a reduction from 1 to 5 mph, and only a few locations had more than 10 mph reduction.

**School Speed Limit Zone**

A School Speed Zone limit along MNTH 5 for the segment adjacent to the Lake Elmo Elementary School should be further explored. The current speed limit at this location is 40 mph. The school zone speed limit on any given road cannot reduce the existing speed limit by more than 30 mph and cannot be less than 15 mph. The zone is legally defined as the section of roads that abuts the school grounds, or where there is an established school crossing with advance school signs defining the area. The school speed limit is only enforced when children are present, or at certain times of the day and are subject to a double fine for violating. The approval of a School Speed Zone limit must be based upon an engineering and traffic investigation as prescribed by the commissioner of transportation in accordance with MN 169.14.

**Urban Configuration**

Safety strategies associated with effectively lowering vehicle operating speeds include those that change the driver’s perceptions of the safe speed along road segments. These strategies focus on narrowing either the actual width or the effective width or the roadway or reducing the width of the travel lanes. Narrowing the actual width of the road may require reconstruction. Narrowing the effective width would include less costly strategies, such as adding wider edge lines or reducing the number of lanes. In addition, roadway features such as curb and gutter, sidewalks, boulevards and street landscaping provide visual cues to drivers of potential pedestrian activity and encourages lower speeds. Safety strategies that could be included for the MNTH 5 urban segment of corridor could include:

**Curb and Gutter** – The urban configuration for MNTH 5 through Lake Elmo would introduce curb and gutter as a visual cue to the driver that they are entering the more urban center of Lake Elmo compared to the shoulder and ditch section associated with the rural setting of MNTH 5.

**Sidewalks** - Sidewalks are a proven safety strategy. Sidewalks on both sides of a street have been found to significantly reduce occurrences of “walking along the roadway” compared to locations where no sidewalks or walkways exist. Walking along the roadway is a pedestrian crash risk. Research has found...
an 88 percent reduction in “walking along the roadway” pedestrian crashes with the installation of sidewalk and/or walkways on both sides of the road (Source: An Analysis of Factors Contributing to “Walking Along Roadway” Crashes: Research Study and Guidelines for Sidewalks and Walkways. Report No. FHWA-RD-01-101).

**Lighting** - Illumination aids drivers by providing light beyond vehicle lighting to help delineate the roadway and see other vehicles and/or pedestrians. The installation of continuous street lighting along the middle segment would benefit drivers by allowing for better nighttime visibility of potential hazards and would help define this segment of MNTH 5 as urban in an effort to influence speed throughout the corridor.

**Pedestrian Accommodations**

**Crosswalk Location**
The current location of the crosswalk within the bypass lane for the CSAH 17 (Lake Elmo Ave) intersection near the elementary school is not ideal and creates a double-threat for pedestrians with vehicles having the ability to use the bypass lane to pass vehicles stopped for pedestrians at the crosswalk. A crossing location further to the east, out of the bypass lane, would eliminate the double-threat potential and be more in line with the sidewalk currently leading into the Lake Elmo Elementary School doorways.

**Rectangular Flashing Beacon**
Rectangular Rapid Flash Beacons include LEDs that use an irregular flash pattern, similar to emergency flashers on police vehicles. Rectangular Flashing Beacons are a lower cost alternative to traffic signals and have been shown to increase driver yielding behavior at crosswalks significantly when supplementing standard pedestrian crossing warning signs and markings. An example of a RRFB is shown in Figure 15. An FHWA sponsored review of RRFBs in Florida found that crosswalks with RRFBs had increased yielding rates than locations with traditional overhead beacons. RRFB typically cost between $10,000 and $15,000 for two units, one on either side of the street.

**HAWK Signal**
A pedestrian hybrid beacon system, also known as a high-intensity activated crosswalk (HAWK), is a traffic signal installed at mid-block crosswalks. It consists of both a vehicle signal with two side–by-side red lenses and a single yellow lens below the red, and also typical pedestrian signal heads with a WALK signal (see example in Figure 16). The signal remains dark until the pushbutton is activated by a pedestrian and the signal flashes a sequence of amber warning beacons followed by a red STOP beacon, a message that requires motorists to stop for...
pedestrians at the crosswalk. Costs typically range from $50,000 to $120,000 depending on location. Due to the low number of installations and research on the pedestrian hybrid beacon system, they are considered a tried strategy, but with promising results, including the 69 percent reduction in vehicle-pedestrian crashes in one study and a 29 percent reduction in total crashes. In addition, FHWA has endorsed HAWKs as one of their nine proven safety countermeasures.

**Raised Median/Pedestrian Refuge**
Medians and crossing islands (also known as refuge islands or center islands) are raised areas that are constructed in the center portion of a roadway that can serve as a place of refuge for pedestrians who cross the road mid-block or at an intersection. After crossing to the center island, pedestrians wait for motorists to stop or for an adequate gap in traffic before crossing the second half of the street. A median eliminates the need for simultaneous gaps in each direction of traffic reducing the amount of time the pedestrians has to wait to cross.

Medians and raised islands are a proven safety strategy. One study found a 39 to 46 percent reduction in pedestrian-vehicle crashes at unsignalized crosswalks on multi-lane roads (Source: Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines. Report No. FHWA-RD-01-075).

**Intersections**
Two future traffic control alternatives are suggested for the intersections of MNTH 5 and CSAH 17. Both of these intersections had higher than the critical crash rates and currently have the highest volume of approaching traffic. While these locations may not have high enough traffic volumes to meet traffic signal warrants today, it is likely that warrants may be met in the future with the increase in traffic on MNTH 5 and continued development within the City of Lake Elmo. When intersection improvements are
warranted MnDOT evaluates the two traffic control alternatives, discussed below, to determine which option is best for a particular intersection.

**Roundabout:** Roundabouts are proven to reduce all crashes at intersections by 39% and fatal crashes by 89%. They reduce vehicle speeds, have fewer conflict points and reduce collision angles compared to stop sign or traffic signal controlled intersections. The installation of a roundabout at both intersections would also provide opportunity for access management with the installation of a median between roundabouts. Access would then be right-in right-out only with u-turns at the roundabouts. Roundabouts would also help in reducing the speed of traffic in this area of Lake Elmo. Roundabouts at these intersections would require additional right-of-way and further study would be required to better define the impacts.

**Signal:** While traffic signals do not eliminate right angle crashes, they reduce the need for the driver on the minor road to determine a proper gap to merge into traffic. While a roundabout is generally considered a safer form of at-grade intersection, a signalized option should also be considered for these locations based on traffic analysis, land needs, etc. The addition of turn-lanes would impact right-way and access in the intersection area, further study would be required to better define the impacts.

**Access Management**

All three segments have higher than average accesses per mile with the rural segments of the west and east segments at 12 to 13 access per mile versus the statewide average of 8 accesses per mile for rural segments. The urban segment has 40 accesses per mile which is higher than the statewide average of 28 accesses per mile for urban segments.

Additional coordination between MnDOT, the City of Lake Elmo and adjacent parcel owners should be considered to attempt to reduce the number of accesses by closing or combining access, especially in the middle segment of the study area. Access location and consolidation should also be considered with any new development along the corridor.

**Street Network**

The MNTH 5 corridor is an important corridor because of the limited east-west connections within the region that provide connections to Interstate 694. The City of Lake Elmo should continue to plan for additional north/south connections between the three major east-west connections of MNTH 36, MNTH 5 and County Highway 10 (10th St.) while also looking for opportunities to increase the local east-west street network.
Conclusions
The key facts regarding traffic safety and operations in the MNTH 5 corridor that influenced the discussion and development of potential mitigation strategies include the following:

Safety
- While safety improvements are designed to reduce the risk of a crash, they cannot fully eliminate the risk of a crash.
- The Middle and East segments have crash rates higher than what is expected and the predominant crash type is a Rear End collision. The fraction of severe crashes is less than what is expected.
- The West segment has a crash rate lower than what is expected, but the fraction of severe crashes (4%) is somewhat higher than the expected value (2.8%). Rear End crashes are over represented in this segment and include one severe injury rear end crash. The one fatal crash on this segment involved a vehicle crossing the centerline of the roadway.
- Over 90% of the crashes in the corridor are intersection related.
- The intersection at Jamaca Avenue had the highest crash rate of any intersection in the corridor, but this rate has dropped substantially since the construction of the roundabout. The intersection with Manning Avenue currently has the highest frequency of crashes of any intersection in the corridor (4 crashes per year) but the rate is approximately equal to what is expected for signalized intersections.
- Nine of the remaining intersections (31st Street, Stillwater Lane West, Kelvin Avenue, Stillwater Lane East, Klondike Avenue, Laverne Avenue, Layton Avenue, 39th Street, and Little Bluestem Trail) average approximately one or fewer crashes per year and the rate at each of these locations is approximately equal to or less than the expected value.
- The two intersections with CSAH 17 (Lake Elmo Avenue) have crash rates higher than expected, but these intersections average between 2 and 3 crashes per year and only one crash in the past ten years has involved a serious injury.
- While there have been no pedestrian crashes, except at the Manning Avenue intersection, there is a perceived safety issue at the existing crosswalk near the Lake Elmo Elementary School.

Traffic Volume & Operation
- The current volume of traffic on MNTH 5 is between 11,000 and 13,000 vehicles per day.
- Due to growth in Lake Elmo and in the East Metro area, the daily volume of traffic is expected to grow to approximately 16,000 vehicles per day by the year 2029.
- The combination of current volume and the current basic design of the roadway being limited to 2-lanes results in a minor amount of congestion (Level of Service D) during peak traffic periods. The forecast growth in traffic would also be expected to increase the amount of congestion so that the operation of a 2-lane MNTH 5 would be expected to approach LOS F by the year 2029.
- Traffic operations in the vicinity of the elementary school were observed to work very well with the arrivals and departures focused on the north side of the building. Minor queues were observed at the Laverne Avenue intersection during the departure period, but the queues dissipated in a short amount of time.
**Vehicle Speeds**

- The current speed limits (55 mph in the West segment, 40 mph in the Middle segment and 50 mph in the East segment) all appear to be reasonable based on a comparison of the characteristics of the speed profiles - the speed limits all approximate the 85th percentile speeds and are in the 10 mph pace and speeds are very uniform with over 85% of the vehicles traveling in the pace.
- The current speed limits are also consistent with the image of the roadway that is apparent to drivers – a rural design with wide paved shoulders and grass ditches.

**Access**

- The density of access is higher than for similar roadways and research indicates that high levels of access are associated with higher rates of crashes and a higher fraction of Rear End and Right Angle crashes.

**Road Network**

- In the City of Lake Elmo the local road network is underdeveloped, with too few minor arterials and collector roadways, forcing vehicles onto the few continuous roadways that do provide connections to regional road network, such as MNTH 5. As a result, traffic volumes are higher on MNTH 5 than if alternatives existed and ultimately create issues for vehicles on local streets trying to access MNTH 5.

**Recommendations**

The RSA Team developed a list of suggested improvements to address the identified safety and operational deficiencies noted in the MNTH 5 corridor. The key components include converting MNTH 5 from a 2-lane roadway to a 3-lane roadway with a center two-way left turn lane and developing and implementing access management and street network plans for the City of Lake Elmo.

The rationale in support of converting to a 3-lane roadway is the superior safety performance (especially compared to the Middle segment of MNTH 5) and the configuration’s ability to reduce Rear End crashes and mitigate the effects of high access density. In addition, there is anecdotal information that suggests that implementation of 3-lane roadways results in a 3 to 5 mph drop in vehicle speeds, which may relate to drivers finding that these roadways present more of an urban image. The suggested access management and street network plans are related to the high levels of accessibility along the corridor and the lack of a supporting road network.

The City of Lake Elmo is developing a plan to determine how future development will occur in the Village Planning Area that includes the downtown area and MNTH 5. The Village Plan provides the city’s vision of how they see Stillwater Boulevard (MNTH 5) serving the community and suggests improvements along the roadway to provide a more traditional Main Street design. These city goals and objectives should be considered by MnDOT when changes to MNTH 5 are considered.

The RSA Team considered the costs and feasibility of implementing specific strategies at specific locations in the corridor and suggests a potential implementation plan for the Short Term (1 to 5 years),
Mid Term (5 to 10 years) and Long Term (more than 10 years) time frame. A summary of the suggested implementation plan is included in Table 7.

**Short Term (1-5 years)**
- Restripe the Middle segment as a 3-lane cross-section as part of MnDOT’s planned 2013 resurfacing project.
  Note: conversion to a 3-lane will eliminate existing right-turn lanes, separate projects should be pursued to replace them as needed.
- Add center line rumble stripes in the east and west segments with MnDOT’s 2013 resurfacing project in 2013.
- Develop an access management plan for the corridor.
- Develop a Pedestrian and Bicycle Plan to provide pedestrian and bicycle connections, especially to/from the Lake Elmo Elementary School and plan for future sidewalks along MNTH 5.
- Develop a street network plan for the corridor (that identifies future intersection locations, design and control).
- Add a dynamic speed feedback sign westbound at the 50 mph/40 mph transition.
- Evaluate a school zone speed limit.
- Address pedestrian activity around the elementary school by moving the existing crosswalk to the east, adding a Rectangular Rapid Flash Beacon or HAWK signal and consider adding a center pedestrian refuge island and other sidewalk connections to improve the crossing and connections.
- Consideration was given to lowering the current speed limits but was rejected because there is no evidence that changing signs will change driver behavior and because sustained increased enforcement is not likely due to insufficient staff to increase current levels of enforcement.
- Reevaluate the speed limit after the three-lane is implemented.

**Mid Term (5-10 years)**
- Begin implementation of the access management plan – relocating and consolidating driveways.
- Continue monitoring speeds on all segments.
- East segment - implement a 3-lane cross-section.
- West segment - create a 4’ buffer in the center and with center rumble strips.

**Long Term (10+ years)**
- Reconstruct the Middle to an urban section with curb/gutter, boulevards, sidewalks and street lights.
- Reconstruct the West segment to more positively prevent cross centerline crashes – the two most effective options would involve either creating a 12’ wide buffer similar to the segment of MNTH 5 east of CSAH 15 or developing the segment as a 2+1 roadway with a cable barrier in the center.  In either case, the design supports managing access and allows the development of a left turn lane at Kelvin Avenue.
- Address traffic control at the intersections with CSAH 17 (Lake Elmo Avenue) – either through traffic control with the addition of traffic signals (conduct traffic operations studies to determine if right
turn lanes are needed in addition to left turn lanes) or through geometry with the addition of roundabouts.

- Continue implementation of the corridor access management plan.
- Continue implementation of the street network plan for the City of Lake Elmo.
- Monitor speed limits along MNTH 5, especially after reconstruction of the middle segment, to determine if reduction in speed limit is appropriate.

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<th>Mid Term Actions (5 to 10 years)</th>
<th>Long Term Actions (10+ years)</th>
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<tr>
<td>3-lane conversion (middle segments)</td>
<td>Begin Implementation of Access Management Plan and Street Network Development</td>
<td>Reconstruct Middle section with Urban Amenities</td>
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<td>Develop Plan for Street Network</td>
<td>4’median buffer (west segment)</td>
<td>Reconstruct West Segment with either 12’ buffer or 2+1 design</td>
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<td>Develop Access Management Plan</td>
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<td>Implement changes to traffic control at CSAH 17 intersections (roundabout or signals)</td>
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<td>Dynamic Speed Sign for WB at speed transition</td>
<td>Continue Monitoring Speeds</td>
<td>Consider Speed Limit modifications based on results of speed studies after reconstruction</td>
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<td>Evaluate School Speed Zone</td>
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<td>Move Crosswalk east, out of bypass lane</td>
<td>Implement Pedestrian and Bicycle Plan</td>
<td>Include sidewalks as part of the MNTH 5 reconstruction</td>
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<td>Develop Pedestrian and Bicycle Plan for sidewalk and trail connections</td>
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<td>Add Pedestrian Refuge Island</td>
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<tr>
<td>Add Rapid Flashing Beacon Pedestrian Crossings</td>
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Resources

- MnDOT Traffic Safety Website: http://www.dot.state.mn.us/trafficeng/safety/
- Crash Modification Factors Clearinghouse: http://www.cmfclearinghouse.org/
- Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Executive Summary and Recommended Guidelines. Report No. FHWA-RD-01-075