Duluth-Superior Transportation Systems Management

TSM Assessment of MIC Roadways in Minnesota 2007

December 2007

TSM Assessment for MIC Roadways in Minnesota 2007

Prepared by the

Duluth-Superior Metropolitan Interstate Council

Duluth and Superior urban area communities cooperating in planning and development through a joint venture of the Arrowhead Regional Development Commission and the Northwest Regional Planning Commission

December 2007

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please visit **www.dsmic.org/tsm**

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1. Background

Transportation Systems Management (TSM)

This document contains findings from the MIC's 2007 TSM assessment. It identifies a potential *locations of concern* along Minnesota roadways within the MIC area. The locations are ranked according to their potential needs for capacity and/or safety improvements. The rankings, and information accompanying each location, are intended to assist Wisconsin jurisdictions in the MIC area as they consider future transportation improvement projects.

Transportation Systems Management (TSM) is an objective identified in the Duluth-Superior Long Range Transportation Plan 2005-2030 for achieving the goals of safety and efficiency. TSM is an approach in planning and engineering aimed at optimizing the safety and efficiency of an existing transportation system through the use of low-cost (yet, effective) improvements, as opposed to expensive capital improvements. Some examples of TSM related actions are: striping in improved roadway geometry, applying access management techniques, and improving coordination between traffic signals.

TSM planning is something the MIC did actively in the past. Prior to the federal government's passing of ISTEA in 1991, the MIC was producing updated TSM plans (1980 and 1989) to serve as the short-range element of the Duluth-Superior long-range transportation plan. Minnesota jurisdictions had input in the development of these plans through their involvement in a TSM advisory committee that worked to identify "problem sites" in the metro area and then recommend specific TSM actions to address them. The 2007 MIC TSM assessment is essentially the same process, only the input of jurisdictions is sought after potential problem locations have been identified using a quantitative analysis, the methodology of which is described in the following pages.

Strengths & limitations of the 2007 TSM analysis

The TSM assessment was designed to objectively identify and prioritize locations in the MIC area through the use of quantitative measures. By performing such an analysis at the front end of the TSM planning process, two advantages are gained. First, potential problems occurring on roadways of lesser profile that might otherwise go unnoticed can be identified. Secondly, locations can be identified much more quickly than with the MIC's earlier TSM process, which required committee members from jurisdictions to come together in the absence of quantitative measures and find consensus as to what locations should be analyzed.

Being that 2007 is the first year that the MIC has done a quantitative TSM assessment, it is anticipated that potential limitations with some of the methods may be found as the TSM process moves foreward. Because of this, **the MIC encourages area jurisdictions and local transportation agencies to scrutinize the methods used in the analysis and respond**, so that future iterations of the TSM assessment can be improved upon and made as relevant as can be to transportation planning in the Duluth-Superior metropolitan area.

One such limitation with the 2007 TSM assessment that has already been identified is the absence of transit in the analysis. Transit related factors were not included in the quantitative assessment used to identify and prioritize the 2007 *locations of concern*. Measures such as the existence or absence of a transit route along a roadway, the location of bus stops relative to an unsafe location, etc. will be considered as factors to be included in future assessments, and the MIC will continue to work with the Duluth Transit Authority (DTA) to establish the best ways to represent transit in the TSM assessment.

2. Methods

Data used for the 2007 TSM analysis

The 2007 TSM analysis began with a study of five consecutive years of available crash data (2001-2005). Information gathered from the crash data was used throughout the study to identify the *locations of concern* for 2007 and to help determine potential deficiencies at those locations. Traffic volume data provided by MnDOT was also used, while information regarding functional classification and level of service (LOS) was taken from the MIC's long range plan document (Table 2.1).

Table 2.1 Sources of data used in the TSM study
Functional Classification - Duluth-Superior Long Range Transportation Plan 2005-2030
Level of Service (LOS) - Duluth-Superior Long Range Transportation Plan 2005-2030
Annual Average Daily Traffic (AADT) - MnDOT; 1999 & 2003
Crash Data - MnDOT; years 2001-2005

Steps Involved in the 2007 TSM analysis

A summary of the steps used in the 2007 TSM assessment follows. Each step represents a series of tasks involved in carrying out the actions described in the headings.

Step 1. Selecting "high-crash" locations

The term *high-crash* was applied to all locations in the MIC area that had three or more crashes occurring within 105 ft of each other during the year 2005. Three crashes/year was only the threshold used to determine which locations would enter the TSM analysis. Although the term "high-crash" was applied, it is <u>not</u> meant to distinguish the locations as necessarily hazardous without further study (see discussion on pages 5 and 6). All of the *high-crash* locations that entered the TSM analysis are listed in Table 2.2.

Table 2.2 "High-crash" locations of 2005 (listed in no particular order)

1. London Rd. & 21st Ave. E
2. W Arrowhead Rd. & Kenwood Ave.
3. Miller Trunk Hwy. & Maple Grove Rd.
4. Maple Grove Rd. & Haines Rd.
5. Grand Ave. & 40th Ave. W
6. 4th St. & 6th Ave. E
7. Miller Trunk Hwy. & Arrowhead Rd.
8. Miller Trunk Hwy. & Hwy. 194
9. Miller Trunk Hwy. & Ugstad Rd.
10. Haines Rd. & Anderson Rd.
11. W 7th St. & W Skyline Pkwy.
12. N Central Entrance & Mesaba Ave.
13. Haines Rd. & Arrowhead Rd.
14. Miller Trunk Hwy. & Haines Rd.
15. Central Entrance. & Anderson Rd.
16. Grand Ave. & 46th Ave. W
17. Central Entrance & Blackman Ave.
18. Midway Rd. & N Cloquet Rd.
19. Haines Rd. & Mall Dr.
20. College St. & 19th Ave. E
21. US Hwy. 2 & Hwy. 194
22. Rice Lake Rd. & Skyline Pkwy.
23. US Hwy. 2 & Midway Rd.
24. Midway Rd. & Maple Grove Rd.
25. Maple Grove Rd. & Stebner Rd.
26. Midway Rd. & Becks Rd.
27. W Railroad St. & Canal Park Dr.
28. Piedmont Ave. (between 1st & 2nd)

Step 2: Identifying locations of concern

Because the MIC's TSM analysis is intended to be done annually or semi-annually, it was decided that the number of locations to be analyzed in one year's study should be kept manageable. Therefore, each *high-crash* location was measured against some additional threshold values in order to further shorten the number to be analyzed. A set of categorical distinctions (e.g. level of service), as well as measurable attributes (e.g. crash rate; Figure 2.1), were used for these threshold values (Table 2.3).

Table 2.3 Threshold values

ATTRIBUTE	THRESHOLD
Level of service (LOS)	≤ D
5 year crash rate	≥ 1.00
5 year avg. crash severity	≥ 3.00
Current year's crash rate	≥ 1.00
Current year's avg. severity	≥ 3.00
5 year trend in crash rate	> 0

Locations had to meet or exceed at least one threshold in order to be considered a *location of concern.* Thirteen locations either met or exceeded one of the threshold values. These locations are shown in Map 2.1 on page 7.

Figure 2.1 Measured attributes

Crash rate for spot locations

$$CR_{spot} = \frac{1{,}000{,}000 \times CRA}{365 \times AADT}$$

CRA = average annual number of crashes
AADT = average annual daily traffic

Average crash severity

$$SEV_{avg} = \frac{(10)K+(8)A+(6)B+(3)C+PD}{\text{total crashes}}$$

K = total number of fatality crashes
A = total number of incapacitating injury crashes
B = total number of non-incapacitating injury crashes
C = total number of possible injury crashes
PD = total number of property damage only crashes

Average annual rate increase

$$CR = (\Delta CR_{'02}+\Delta CR_{'03}+\Delta CR_{'04}+\Delta CR_{'05}) - \Delta CR_{'02}$$

ΔCR_{year} = change in crash rate from previous year

What are acceptable numbers?

Crash statistics are relative. No universal critical value exists that can tell us if the amounts or types of crashes at a particular location are unacceptable. However,

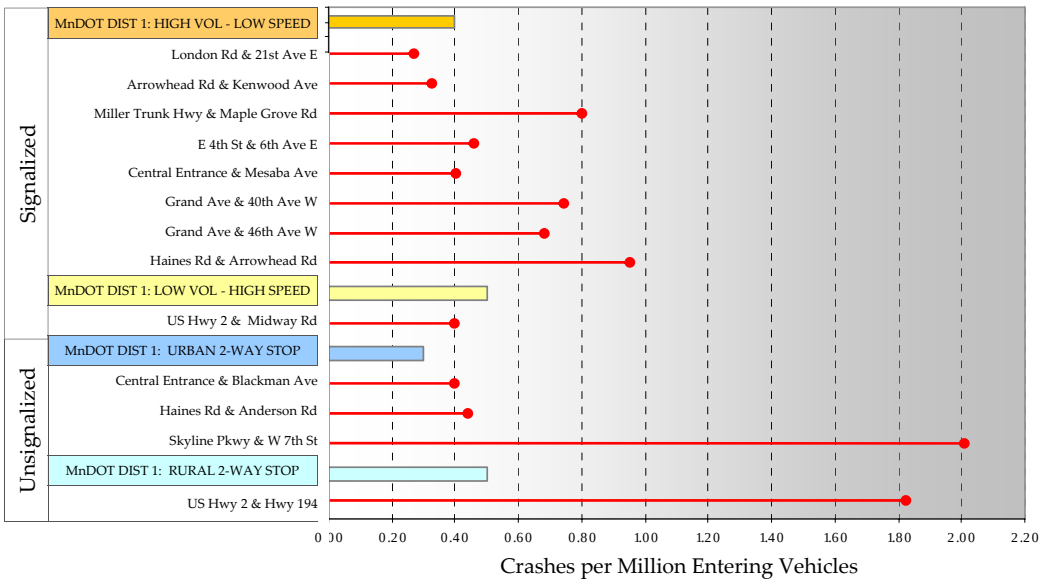
Table 2.4 Average values for area intersections (MnDOT 2003-2005)

SIGNALZED INTERSECTIONS	REGION	CRASH RATE	AVG. SEVERITY
High volume (>15,000 ADT) & high speed (>45 mph)	MnDOT District 1	0.60	2.38
	Statewide	0.80	2.03
High volume (>15,000 ADT) & low speed (<45 mph)	MnDOT District 1	0.40	2.39
	Statewide	0.70	2.02
Low volume (<15,000 ADT) & high speed (>45 mph)	MnDOT District 1	0.50	2.50
	Statewide	0.70	2.22
Low volume (<15,000 ADT) & low speed (<45 mph)	MnDOT District 1	0.50	1.96
	Statewide	0.60	1.96

UNSIGNALIZED INTERSECTIONS	REGION	CRASH RATE	AVG. SEVERITY
4-way stop	MnDOT District 1	0.80	2.60
	Statewide	0.60	1.95
Urban 2-way stop	MnDOT District 1	0.30	2.26
	Statewide	0.30	2.04
Rural 2-way stop	MnDOT District 1	0.50	2.64
	Statewide	0.30	2.49

Crash rates for the locations identified in this study are compared below in Figure 2.2 to averages for the NE MN region. The MIC's TSM analysis does not make claims as to whether any of the rates equals a deficiency in safety, but it does use the values to help prioritize the locations relative to each other.

Figure 2.2 Area crash rates compared to MnDOT District 1 averages*



* MnDOT values represent 3-year averages (2003-2005) versus the MIC's 5-year averages (2001-2005).

Step 3. Prioritizing the locations of concern

Next, the *locations of concern* were prioritized by applying weights to each of the threshold values used in Step 2 (Table 2.4). **Bias (i.e. weight) was given first to the poorest levels of service,** since improvements to traffic flow are expected to have more of an impact on system performance. The second highest weights were given to the 5 year crash rate and severity scores. The prioritized list is presented in Table 2.6 and Map 2.1 below.

Table 2.5 Weight values

ATTRIBUTE	WEIGHT
Level of service (LOS)	x 0.50
5 year crash rate	x 0.30
5 year avg. crash severity	x 0.30
Current year's crash rate	x 0.10
Current year's avg. severity	x 0.10
5 year trend in crash rate	x 0.10

Map 2.1 MIC MN Locations of Concern for 2007

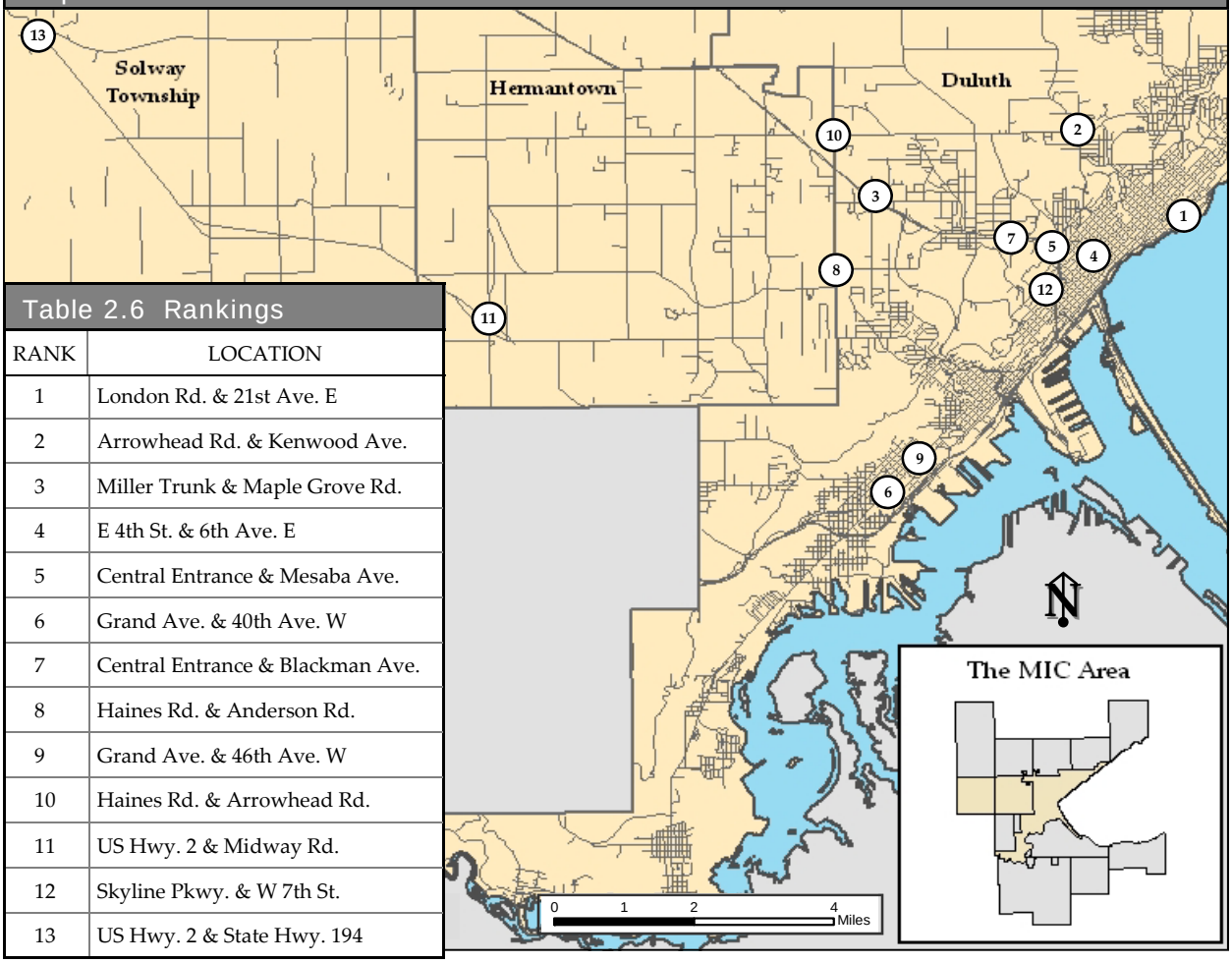


Table 2.6 Rankings

RANK	LOCATION
1	London Rd. & 21st Ave. E
2	Arrowhead Rd. & Kenwood Ave.
3	Miller Trunk & Maple Grove Rd.
4	E 4th St. & 6th Ave. E
5	Central Entrance & Mesaba Ave.
6	Grand Ave. & 40th Ave. W
7	Central Entrance & Blackman Ave.
8	Haines Rd. & Anderson Rd.
9	Grand Ave. & 46th Ave. W
10	Haines Rd. & Arrowhead Rd.
11	US Hwy. 2 & Midway Rd.
12	Skyline Pkwy. & W 7th St.
13	US Hwy. 2 & State Hwy. 194

Step 4. Studying the crash trends

After prioritizing the *locations of concern*, **the 5 year crash history of each location was examined to identify any patterns that would suggest the existence of specific problems.** Factors such as the most prevalent crash types, times of the day when most crashes occurred, weather conditions, etc. were noted, while relationships between other factors such as the direction of travel and the AADT of a roadway were also examined. A diagram of significant patterns was then developed for each location (Figure 2.3).

Figure 2.3 Crash pattern diagram

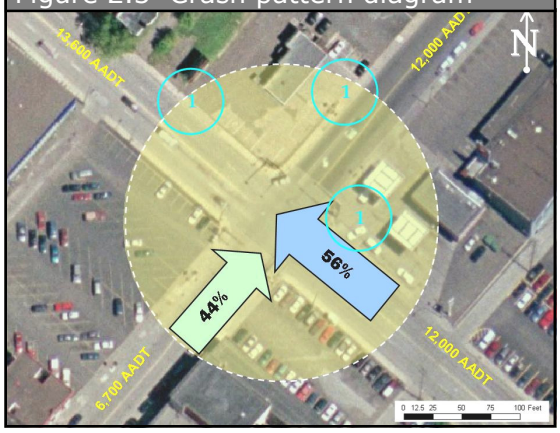


Figure 2.4 On-site observations

Step 5. On-site assessments & team discussions

The crash pattern diagrams were taken to each location, where **MIC staff made on-site observations about existing conditions, and looked for any other factors that might be contributing to the patterns observed in the crash data**, as well as possible safety or efficiency issues not reflected in the data. Staff observed traffic movements, signage and signal arrangements, potential sight obstructions, conditions of pavement markings, etc. After the on-site visits were completed, the crash pattern diagrams were presented to the rest of the MIC staff, who then shared observations regarding each of the locations. The group then identified a series of possible treatments to recommend.

Step 6. Creating and updating a TSM database

In order to continue monitoring system performance and track the success of TSM actions that eventually become implemented, a spreadsheet database was created from the findings of the TSM studies. Using the database for subsequent TSM studies will ensure that all values used to identify and prioritize the *locations of concern* will remain accessible for further analyses and allow comparisons to be made if certain locations continue to reappear as *locations of concern*.

Any intersections or segments that receive improvements after being studied will continue to be analyzed for at least three consecutive TSM studies, whether or not they continue to meet the threshold of three or more crashes per year. This will be done to attempt to gauge the effectiveness of those treatments.

In the pages that follow, a summary of the findings for each *location of concern* from 2007 are presented. Deficiencies identified at some locations have already been, or are scheduled to be, addressed through a variety of improvement projects. Those locations will continue to be monitored in upcoming TSM studies, and their rankings will be included in the updated database.

A copy of the spreadsheet database can be found on the following page (Table 2.6). It should be noted that inconsistencies may exist between the data presented and similar data used at other agencies. This is likely due to differing sources of the data and/or different times at which the data was gathered. Ultimately, the purpose of the TSM study is not to generate values that represent the highest degree of precision, but rather to identify and prioritize locations of potential deficiencies relative to each other using an objective and consistent method.

Table 2.7 MIC TSM database - Minnesota area - 2007

2005 Rank	2006 Rank	Location	2001 Crashes	2001 ADT	2001 Crash Rate	2001 Rate Change	2001 Avg Severity	2002 Crashes	2002 ADT	2002 Crash Rate	2002 Rate Change	2002 Avg Severity	2003 Crashes	2003 ADT	2003 Crash Rate	2003 Rate Change	2003 Avg Severity	2004 Crashes	2004 ADT	2004 Crash Rate	2004 Rate Change	2004 Avg Severity	2005 Crashes	2005 ADT	2005 Crash Rate	2005 Rate Change	2005 Avg Severity
NA	1	London Rd & 21st Ave E	2	26,200	0.21	NA	2.00	4	26,200	0.42	0.21	5.75	2	27,950	0.20	-0.22	3.50	1	27,950	0.10	-0.10	1.00	4	27,950	0.39	0.29	1.50
NA	2	Arrowhead Rd & Kenwood Ave	3	22,575	0.36	NA	2.67	4	22,575	0.49	0.12	5.25	3	24,625	0.33	-0.15	3.00	2	24,625	0.22	-0.11	2.00	3	24,625	0.33	0.11	3.33
NA	3	Miller Trunk Hwy & Maple Grove Rd	9	25,650	0.96	NA	2.88	7	25,650	0.75	-0.21	4.00	9	27,050	0.91	0.16	2.33	9	27,050	0.91	0.00	1.88	6	27,050	0.61	-0.30	1.66
NA	4	E 4th St & 6th Ave E	1	17,950	0.15	NA	1.00	4	17,950	0.61	0.46	4.00	2	22,150	0.25	-0.36	1.00	6	22,150	0.74	0.49	3.66	5	22,150	0.62	-0.12	1.40
NA	5	Central Entrance & Mesaba Ave	4	27,915	0.39	NA	2.75	2	27,915	0.20	-0.20	1.00	8	32,600	0.67	0.48	3.13	4	32,600	0.34	-0.34	2.50	5	32,600	0.42	0.08	2.00
NA	6	Grand Ave & 40th Ave W	3	14,300	0.57	NA	5.00	5	14,300	0.96	0.38	5.40	5	19,250	0.71	-0.25	2.80	9	19,250	1.28	0.57	2.78	4	19,250	0.57	-0.71	2.50
NA	7	Central Entrance & Blackman Ave	0	18,200	0.00	NA	0.00	2	18,200	0.30	0.30	2.00	2	19,800	0.28	-0.02	2.00	1	19,800	0.14	-0.14	3.00	3	19,800	0.42	0.28	3.00
NA	8	Haines Rd & Anderson Rd	2	14,100	0.39	NA	2.00	3	14,100	0.58	0.19	1.67	0	14,100	0.00	-0.58	0.00	1	14,100	0.19	0.19	1.00	5	14,100	0.97	0.78	3.60
NA	9	Grand Ave & 46th Ave W	3	12,250	0.67	NA	2.67	4	12,250	0.89	0.22	3.50	7	18,550	1.03	0.14	4.14	6	18,550	0.89	-0.15	2.60	3	18,550	0.44	-0.44	4.00
NA	10	Haines Rd & W Arrowhead Rd	3	16,375	0.50	NA	2.33	10	16,375	1.67	1.17	3.78	5	15,600	0.88	-0.79	2.00	6	15,600	1.05	0.18	3.40	3	15,600	0.53	-0.53	1.67
NA	11	US Hwy 2 & Midway Rd	0	10,200	0.00	NA	0.00	0	10,200	0.00	0.00	0.00	2	11,125	0.49	0.49	3.00	3	11,125	0.74	0.25	3.33	3	11,125	0.74	0.00	3.00
NA	12	Skyline Pkwy & W 7th St	0	2,375	0.00	NA	0.00	1	2,375	1.15	1.15	1.00	4	2,675	4.10	2.94	4.00	2	2,675	2.05	-2.05	2.00	3	2,675	3.07	1.02	1.67
NA	13	US Hwy 2 & State Hwy 194	3	5000	1.64	NA	1.00	4	5000	2.19	0.55	1.50	3	5,435	1.51	-0.68	2.33	4	5,435	2.02	0.50	2.75	4	5,435	2.02	0.00	1.50

2005 Rank	2006 Rank	Location	MEASURED CRITERIA: 2005 Crash Rate	2005 Avg Severity	5 Yr Crash Rate Trend	5 Yr Avg Severity	Func. Class.	L.O.S.	POINT SCORE: 2005 Crash Rate	2005 Avg Severity	5 Yr Crash Rate Trend	5 Yr Avg Severity	Func. Class.	L.O.S.	WEIGHTED SCORE: 2005 Crash Rate	2005 Avg Severity	5 Yr Crash Rate Trend	5 Yr Avg Severity	Func. Class.	L.O.S.	TOTAL WEIGHT SCORE
NA	1	London Rd & 21st Ave E	0.39	1.50	-0.16	2.8	Min Art/Min Art	F	1	1	2	2	8	10	0.10	0.10	0.60	0.60	0.80	5.00	**7.20**
NA	2	Arrowhead Rd & Kenwood Ave	0.33	3.33	-0.13	3.3	Min Art/Min Art	E	1	4	2	4	8	8	0.10	0.40	0.60	1.20	0.80	4.00	**7.10**
NA	3	Miller Trunk Hwy & Maple Grove Rd	0.61	1.66	0.13	2.6	Princ Art/Minor Art	D	2	1	4	2	9	6	0.20	0.10	1.20	0.60	0.90	3.00	**6.00**
NA	4	E 4th St & 6th Ave E	0.62	1.40	-0.34	2.2	Min Art/Min Art	D	2	1	2	2	8	6	0.20	0.10	0.60	0.60	0.80	3.00	**5.30**
NA	5	Central Entrance & Mesaba Ave	0.42	2.00	0.20	2.3	Princ Art/Princ Art	C	1	2	4	2	10	4	0.10	0.20	1.20	0.60	1.00	2.00	**5.10**
NA	6	Grand Ave & 40th Ave W	0.57	2.50	-0.38	3.7	Min Art/Min Art	C	2	2	2	4	8	4	0.20	0.20	0.60	1.20	0.80	2.00	**5.00**
NA	7	Central Entrance & Blackman Ave	0.42	3.00	-0.20	2.0	Princ Art/Local Rd	C	1	4	2	2	6	4	0.10	0.40	0.60	0.60	0.60	2.00	**4.30**
NA	8	Haines Rd & Anderson Rd	0.97	3.60	-0.05	1.7	Min Art/Maj Coll	C	2	4	2	1	7	4	0.20	0.40	0.60	0.30	0.70	2.00	**4.20**
NA	9	Grand Ave & 46th Ave W	0.44	4.00	-0.28	3.4	Min Art/Maj Coll	A-B	1	6	2	4	7	2	0.10	0.60	0.60	1.20	0.70	1.00	**4.20**
NA	10	Haines Rd & W Arrowhead Rd	0.53	1.67	-1.16	2.6	Min Art/Min Art	C	2	1	1	2	8	4	0.20	0.10	0.30	0.60	0.80	2.00	**4.00**
NA	11	US Hwy 2 & Midway Rd	0.74	3.00	0.18	1.9	Princ Art/Min Art	A-B	2	4	4	1	9	2	0.20	0.40	1.20	0.30	0.90	1.00	**4.00**
NA	12	Skyline Pkwy & W 7th St	3.07	1.67	-0.39	1.7	Maj Coll/Maj Coll	A-B	8	1	2	1	6	2	0.80	0.10	0.60	0.30	0.60	1.00	**3.40**
NA	13	US Hwy 2 & State Hwy 194	2.02	1.50	-0.45	1.8	Princ Art/Princ Art	A-B	6	1	2	1	8	2	0.60	0.10	0.60	0.30	0.80	1.00	**3.40**

= improvements or reconstruction occurred (see individual location summary sheets for more information)

3. Locations of Concern - 2007

An explanation of the summary sheets

This section contains one-page summaries for each *location of concern* that was studied in the 2007 TSM study. Each summary contains a crash trend diagram, a list of crash statistics and a written description of conditions observed, along with some possible TSM treatments. **All percentages provided on the summary sheets refer to a portion of the total crashes that occurred between 2001 and 2005.** Explanations of some of the sheets' features are provided below, while Figure 3.1 on the following page shows where each of the features can be found on the summary sheet.

1. Intersection area (yellow circle)

In order for crashes to be linked to the same location, they had to happen within 105 ft of each other. This is also the recommended threshold-distance in which crashes can be considered related to an urban intersection. The yellow circle in each of the diagrams represents the width of the widest road segment *plus* 105 ft.

2. Crash-trend arrows

The large arrows (containing percentages) show the most prevalent crash types and direction. Straight arrows represent failure-to-yield or "run-thru" crashes, while angled arrows represent turning-movement related crashes. Double arrows represent rear-end crashes. Many vehicles included in the representation of these arrows were likely at fault for the crashes, but since many officers at the scene did not attribute fault to any particular vehicle when filling out their crash reports, it is often unclear which vehicle may have caused the crash.

3. Access-related crashes (small circles)

The smaller, hollow circles identify accesses that were connected to crashes. Numbers inside the circle are the number of crashes related to that access.

4. Items with an asterisk

Items prefaced by an asterisk in the right hand column of the page are those values that either met or exceeded one of the thresholds.

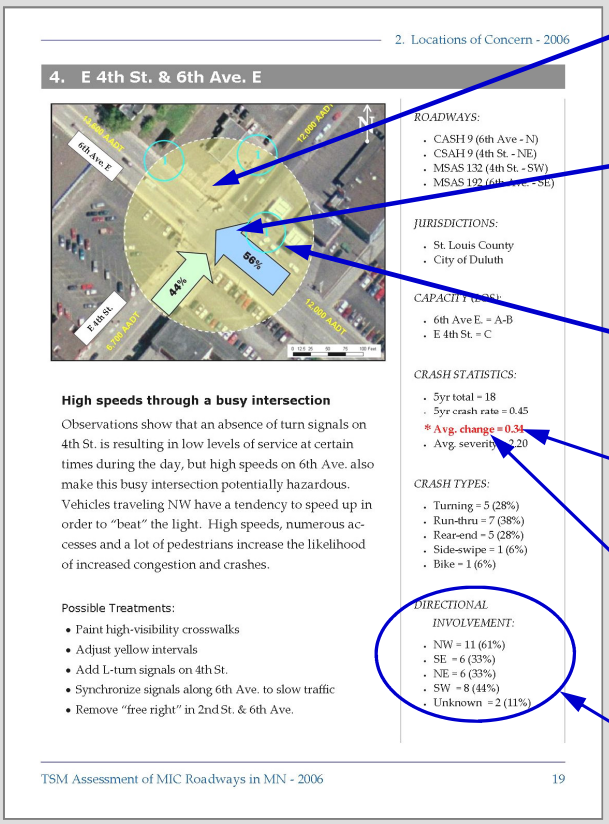
5. Average annual change in crash rate

The crash statistics in the right-hand column provide a general notion of what has occurred at a particular location between 2001-2005. The *5 yr crash rate* is based on an average number of crashes annually, while *Avg. change* represents the average change between crash rates from year to year.

6. Directional involvement

These are the number of crashes that had at least one vehicle traveling in the given direction. It can be useful to contrast the percentages with the AADT numbers.

Figure 3.1 Location of concern summary sheet



2. Locations of Concern - 2006

4. E 4th St. & 6th Ave. E

High speeds through a busy intersection

Observations show that an absence of turn signals on 4th St. is resulting in low levels of service at certain times during the day, but high speeds on 6th Ave. also make this busy intersection potentially hazardous. Vehicles traveling NW have a tendency to speed up in order to "beat" the light. High speeds, numerous accesses and a lot of pedestrians increase the likelihood of increased congestion and crashes.

Possible Treatments:

- Paint high-visibility crosswalks
- Adjust yellow intervals
- Add L-turn signals on 4th St.
- Synchronize signals along 6th Ave. to slow traffic
- Remove "free right" in 2nd St. & 6th Ave.

ROADWAYS:

- CASH 9 (6th Ave - N)
- CSAH 9 (4th St. - NE)
- MSAS 132 (4th St. - SW)
- MSAS 192 (6th Ave - SE)

JURISDICTIONS:

- St. Louis County
- City of Duluth

CAPACITY (LOS):

- 6th Ave E. = A-B
- E 4th St. = C

CRASH STATISTICS:

- 5yr total = 18
- 5yr crash rate = 0.45
- * Avg. change = 0.34
- Avg. severity = 2.20

CRASH TYPES:

- Turning = 5 (28%)
- Run-thru = 7 (38%)
- Rear-end = 5 (28%)
- Side-swipe = 1 (6%)
- Bike = 1 (6%)

DIRECTIONAL INVOLVEMENT:

- NW = 11 (61%)
- SE = 6 (33%)
- NE = 6 (33%)
- SW = 8 (44%)
- Unknown = 2 (11%)

TSM Assessment of MIC Roadways in MN - 2006 19

1. The yellow circle represents 105 feet from the intersection. All crashes occurring within this area were studied.

2. Arrows represent the most prevalent crash patterns.

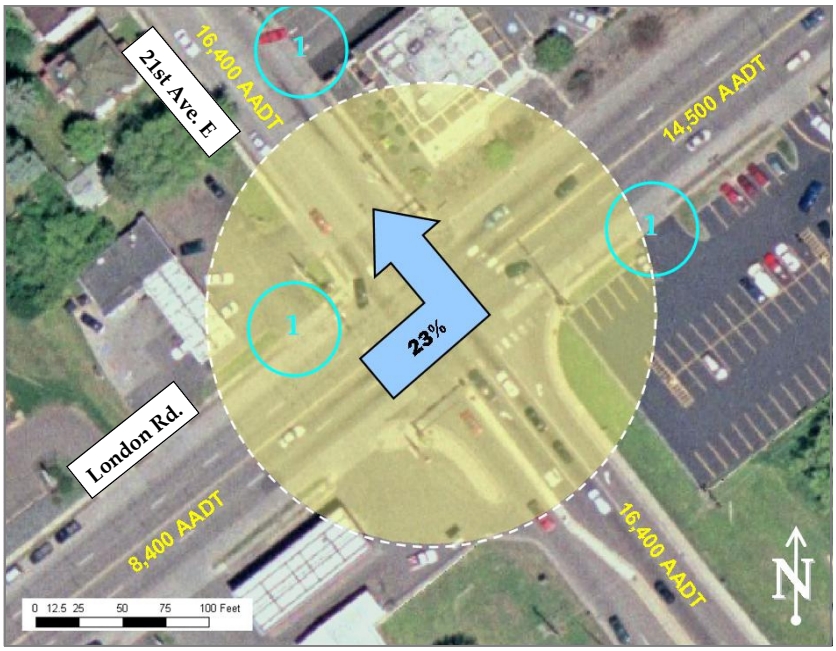
3. Smaller circles show the number of crashes that occurred at a specific access.

4. Items in red are those values that met or exceeded thresholds.

5. *Avg. change* is a measure of how much the crash rate has tended to climb each year.

6. The number of crashes involving at least one vehicle heading in a given direction.

1. London Rd. & 21st Ave. E



Congestion ranks high in the analysis

London Rd. and 21st Ave. E ranks highest in the TSM assessment because of capacity problems. Throughout the day, 21st Ave. E experiences LOS "F".

According to the crash statistics, there are no significant safety issues. Concerns do arise, however, from on-site observations: there is a prevalence of accesses in close proximity to the intersection and the wide roadway tends to encourage higher vehicle speeds through the intersection.

Recommendations:

- Monitor effectiveness of signal-timing.
- Conduct a speed study at intersection.
- Center median to prevent L-turns into accesses.
- Consider 2007 Endion study recommendations.

ROADWAYS:

- MSAS 193 (London Rd.)
- MSAS 152 (21st Ave. E)

JURISDICTIONS:

- City of Duluth

CAPACITY (LOS):

- London Rd. = B

*** 21st Ave. = F**

CRASH STATISTICS:

- 5yr total = 13
- 5yr crash rate = 0.25
- Avg. change = - 0.16
- Avg. severity = 2.80

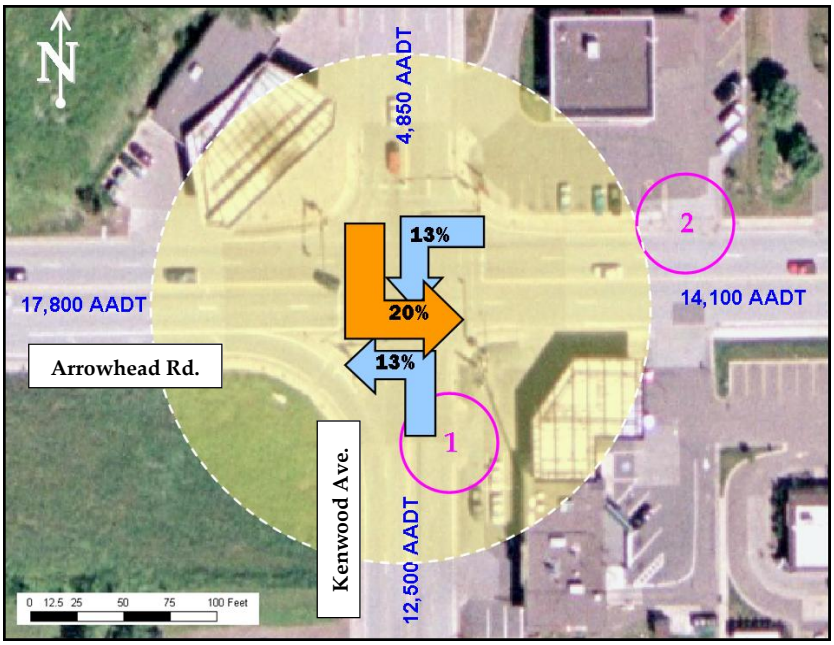
CRASH TYPES:

- Turning = 5 (39%)
- Run-thru = 6 (46%)
- Rear-end = 2 (15%)

DIRECTIONAL INVOLVEMENT:

- NW = 2 (15%)
- SE = 6 (46%)
- NE = 5 (38%
- SW = 5 (38%)
- Unknown = 2 (15%)

2. Arrowhead Rd. & Kenwood Ave.



Are long wait times leading to crashes?

Long queues at the signal cause conflicts with accesses to businesses. To avoid long wait times, drivers may be inclined to speed through yellow lights or attempt left turns without sufficient distance from on-coming traffic.

The prevalence of left turn crashes suggests the need for protected L-turn signals on S-bound Kenwood and E-bound Arrowhead . Access management strategies could also improve flow and mitigate hazards.

Recommendations:

- Add missing L-turn signals.
- Center median to prevent L-turns into accesses.
- Make S-bound Kenwood 2 lanes (designated turn lanes).

ROADWAYS:

- CSAH 3 (Kenwood Ave.)
- MSAS 151 (Kenwood Ave.)
- MSAS 160 (Arrowhead Rd.)

JURISDICTIONS:

- St. Louis County
- City of Duluth

CAPACITY (LOS):

- Kenwood Ave. = A-B
- *** Arrowhead Rd. = E**

CRASH STATISTICS:

- 5yr total = 15
- 5yr crash rate = 0.33
- Avg. change = - 0.13
- *** Avg. severity = 3.30**
- *** 2005 severity = 3.33**

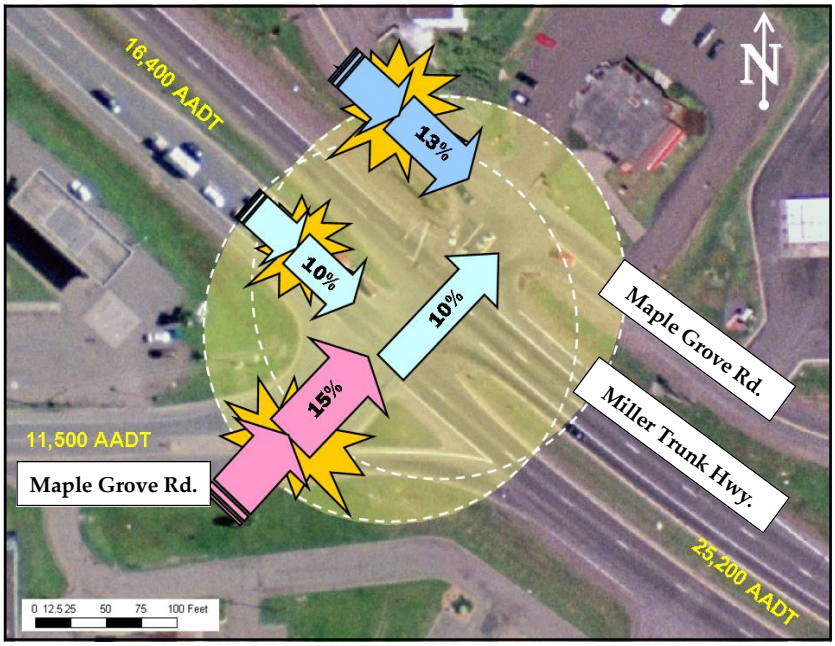
CRASH TYPES:

- Turning = 10 (67%)
- Run-thru = 2 (30%)
- Rear-end = 3 (30%)

DIRECTIONAL INVOLVEMENT:

- N = 5 (33%)
- S = 9 (60%)
- E = 3 (20%
- W = 8 (53%)
- Unknown = 1 (6%)

3. Miller Trunk Hwy. & Maple Grove Rd.



Improvements are already scheduled

In addition to a LOS "D", the intersection of Miller Trunk Highway and Maple Grove Rd. has had significant safety issues and an increasing crash rate as well. MnDOT has reconstruction of this intersection scheduled for 2009, however, and improvements in capacity and safety are expected.

Recommendations:

- No actions needed at this time.

ROADWAYS:

- STH 194 (Miller Trunk)
- CSAH 6 (Maple Grove Rd.)
- MSAS 201 (Maple Grove Rd)

JURISDICTIONS:

- MnDOT District 1
- St. Louis County
- City of Duluth

CAPACITY (LOS):

- *** Miller Trunk Hwy. = D**
- Maple Grove Rd. = A-B

CRASH STATISTICS:

- 5yr total = 40
- *** 5yr crash rate = 0.81**
- Avg. change = 0.13
- Avg. severity = 2.6

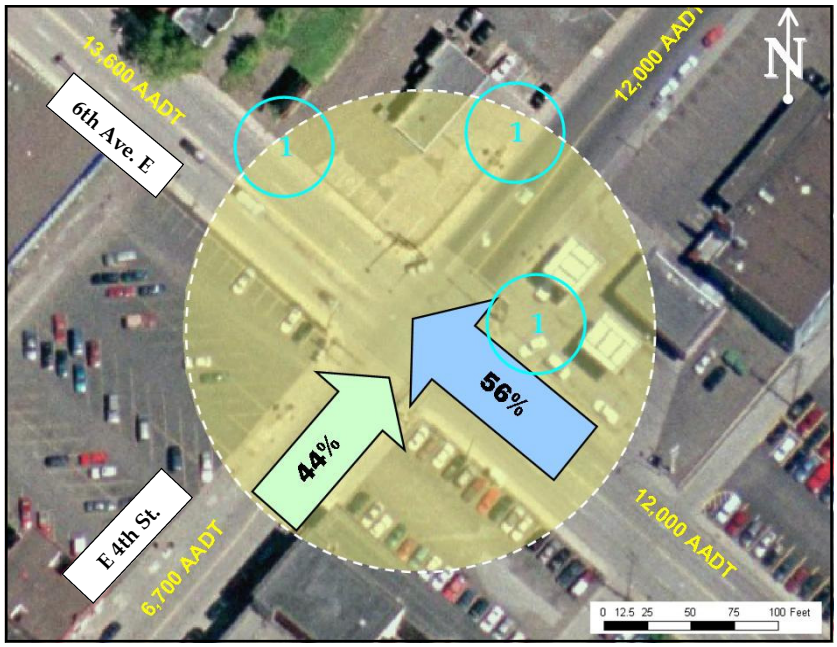
CRASH TYPES:

- Turning = 11 (28%)
- Run-thru = 6 (15%)
- Rear-end = 20 (50%)
- Unknown = 3 (8%)

DIRECTIONAL INVOLVEMENT:

- NW = 12 (30%)
- SE = 31 (78%)
- NE = 22 (55%
- W = 12 (30%)
- Unknown = 3 (8%)

4. E 4th St. & 6th Ave. E



High speeds at a busy intersection

An absence of turn signals on 4th St. seems to be the cause for poor LOS at this intersection, but high speeds on 6th Ave. make it a potentially hazardous location as well. Vehicles traveling NW on 6th Ave. have a tendency to speed up in order to "beat" the light. The city has made recent signal adjustments to mitigate this. However, numerous turning movements combined with numerous pedestrian crossings make this area potentially problematic in terms of both safety and capacity.

Recommendations:

- Add L-turn signal to E 4th St.
- Continue to monitor signal coordination.
- Extend no-parking zone along E 4th St.
- Paint durable-marking crosswalks.

ROADWAYS:

- MSAS 132 (6th Ave - NW)
- CSAH 9 (4th St. - NE)
- MSAS 132 (4th St. - SW)
- MSAS 192 (6th Ave. - SE)

JURISDICTIONS:

- St. Louis County
- City of Duluth

CAPACITY (LOS):

- 6th Ave E. = A-B
- E 4th St. = C

CRASH STATISTICS:

- 5yr total = 18
- 5yr crash rate = 0.45
- *** Avg. change = 0.34**
- Avg. severity = 2.20

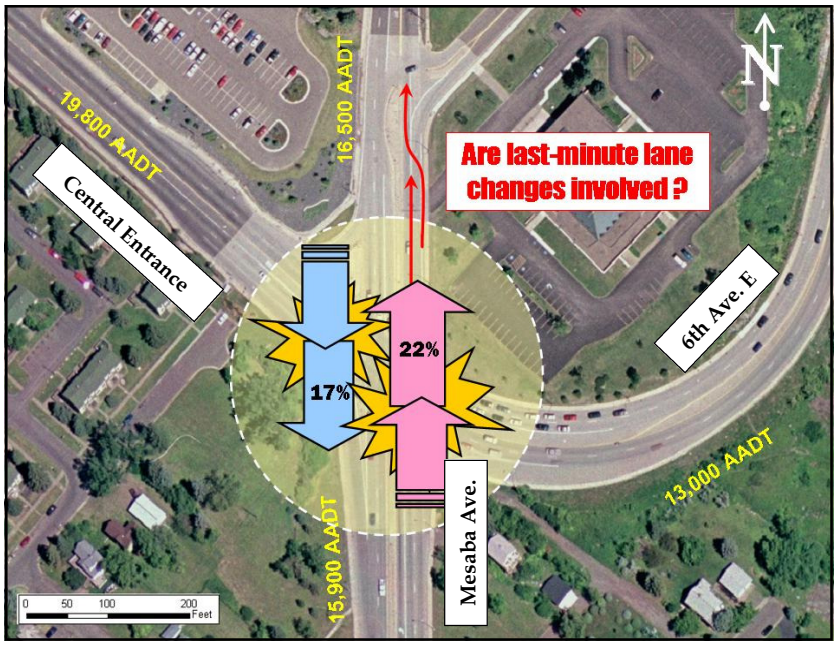
CRASH TYPES:

- Turning = 5 (28%)
- Run-thru = 7 (38%)
- Rear-end = 5 (28%)
- Side-swipe = 1 (6%)
- Bike = 1 (6%)

DIRECTIONAL INVOLVEMENT:

- NW = 11 (61%)
- SE = 6 (33%)
- NE = 6 (33%)
- SW = 8 (44%)
- Unknown = 2 (11%)

5. Central Entrance & Mesaba Ave.



Are lane configurations leading to rear-end crashes?

Rear-end and run-thru crashes account for more than 70% of the total. The sudden convergence of lanes for N-bound traffic on Mesaba Ave. may be a big contributor to the rear-end crashes prevalent for that direction. For S-bound traffic, lengthening the R-turn bay may lessen congestion at peak hours and decrease the amount of crashes.

Recommendations:

- Improve pavement markings (better delineation).
- Increase length of R-turn bay for S-bound traffic..
- Install a splitter-island at Skyline Pkwy. To prevent L-turns onto Rice Lake Rd.

ROADWAYS:

- STH 194 (Cent. Ent.)
- CSAH 4 (Rice Lake Rd.)
- MSAS 132 (6th Ave. E)

JURISDICTIONS:

- MnDOT District 1
- St. Louis County
- City of Duluth

CAPACITY (LOS):

- Central Entrance = C
- Mesaba Ave. = A-B
- Rice Lake Rd. = A-B
- 6th Ave. E = A-B

CRASH STATISTICS:

- 5yr total = 23
- 5yr crash rate = 0.39
- *** Avg. change = 0.20**
- Avg. severity = 2.30

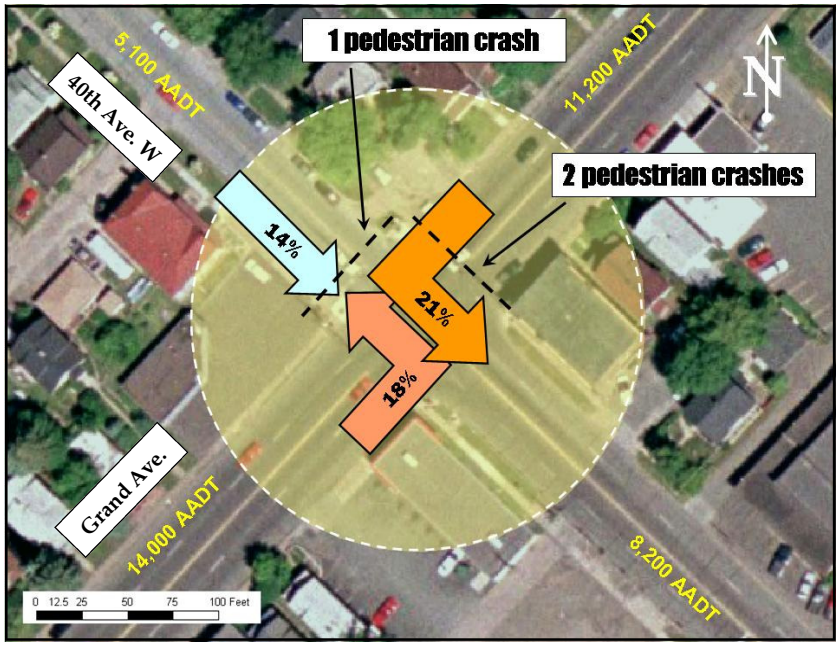
CRASH TYPES:

- Turning = 4 (17%)
- Run-thru = 4 (17%)
- Rear-end = 13 (57%)
- Side-swipe = 3 (13%)
- Off-the-road = 1 (4%)

DIRECTIONAL INVOLVEMENT:

- N = 11 (48%)
- S = 13 (56%)
- E = 8 (35%)
- NW = 5 (22%)
- Unknown = 5 (22%)

6. Grand Ave. & 40th Ave. W



Continue to monitor performance

Grand Ave. underwent a "road diet" between 2005 and 2006, reducing lanes and improving pavement markings. Since 2004, the crash rate at this location has improved significantly, which suggests that the improvements have been effective.

One problem that remains, however. The far right lane of the intersection's SE leg is a lane marked for R-turns and thru movements, but on-street parking along the NW leg does not provide enough space for the N-bound thru movements.

Recommendations:

- Restrict parking on right side of 40th Ave. W.

ROADWAYS:

- CSAH 91 (40th Ave.)
- MSAS 110 (40th Ave.)
- MSAS 126 (Grand Ave.)

JURISDICTIONS:

- St. Louis County
- City of Duluth

CAPACITY (LOS):

- Grand Ave. = A-B
- 40th Ave. W = C

CRASH STATISTICS:

- 5yr total = 26
- 5yr crash rate = 0.74
- Avg. change = -0.38

*** Avg. severity = 3.70**

CRASH TYPES:

- Turning = 13 (50%)
- Run-thru = 10 (38%)
- Pedestrian = 3 (12%)

DIRECTIONAL INVOLVEMENT:

- NW = 3 (12%)
- SE = 18 (69%)
- NE = 16 (61%)
- SW = 7 (27%)
- Unknown = 4 (15%)

7. Central Entrance & Blackman Ave.

An intersection too easy to neglect?

The *Miller Trunk Highway Implementation Plan* (SEH 2002) calls for a signal at this location as a necessary safety measure, but with 19,000 cars/day and only 8 crashes in 5 years, is it an urgent need? Recent changes in the area, however, may justify some action. Some sight obstructions exist for the E-bound and W-bound traffic, and this may be an issue for a rather in-distinguishable intersection. Nearby developments are expected to bring more turning movements to this location.

Recommendations:

- Remove sight obstructions.
- Install a signal.

ROADWAYS:

- STH 194 (Central Ent.)
- local road (Blackman Ave)

JURISDICTIONS:

- MnDOT District 1
- City of Duluth

CAPACITY (LOS):

- Central Entrance = C
- Blackman Ave. = A-B

CRASH STATISTICS:

- 5yr total = 8
- 5yr crash rate = 0.39

*** Avg. change = 0.22**

- Avg. severity = 2.00

*** 2005 severity = 3.00**

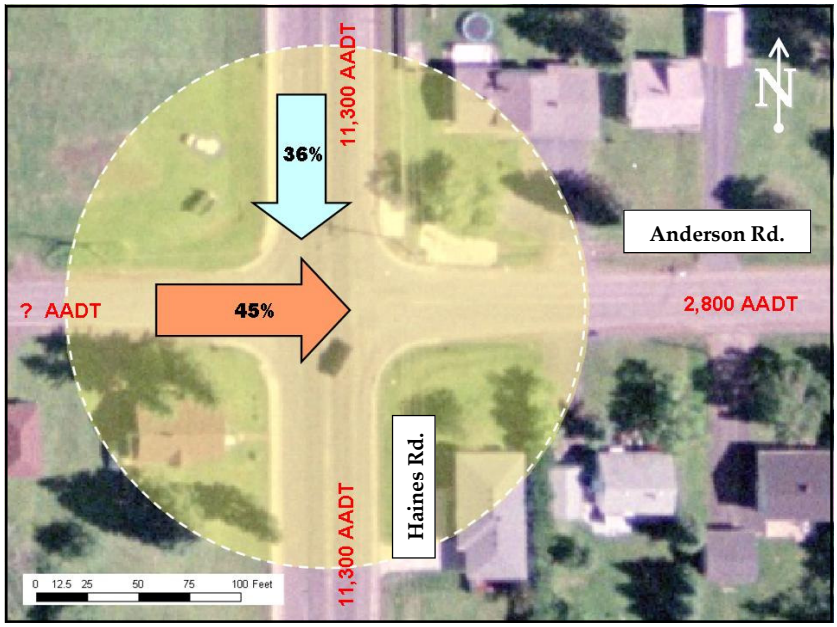
CRASH TYPES:

- Turning = 3 (37%)
- Run-thru = 2 (25%)
- Rear-end = 2 (25%)
- Side-swipe = 1 (13%)

DIRECTIONAL INVOLVEMENT:

- N = 2 (25%)
- S = 3 (38%)
- E = 5 (63%)
- W = 3 (38%)

8. Haines Rd. & Anderson Rd.



A signal is scheduled

The intersection of Haines Rd. and Anderson Rd. meets warrants for a traffic signal, and one is on its way. Installation is scheduled for 2008. TSM actions should be postponed until the effectiveness of the signalization is determined.

Recommendations:

- No actions needed at this time.

ROADWAYS:

- CSAH 91 (Haines Rd.)
- MSAS 198 (Anderson - E)
- local road (Anderson - W)

JURISDICTIONS:

- St. Louis County
- City of Duluth
- City of Hermantown

CAPACITY (LOS):

- Haines Rd. = C
- Anderson Rd. = A-B

CRASH STATISTICS:

- 5yr total = 11
- 5yr crash rate = 0.43
- Avg. change = -0.05
- Avg. severity = 1.70

*** 2005 severity = 3.60**

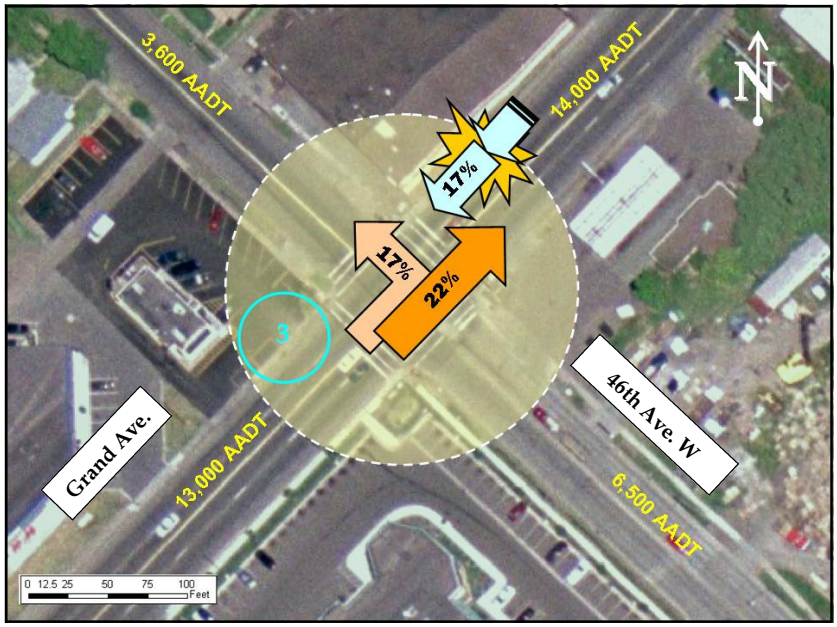
CRASH TYPES:

- Turning = 0 (0%)
- Run-thru = 7 (64%)
- Rear-end = 3 (27%)
- Side-swipe = 1 (9%)

DIRECTIONAL INVOLVEMENT:

- N = 3 (27%)
- S = 8 (73%)
- E = 5 (45%)
- W = 2 (18%)

9. Grand Ave. & 46th Ave. W



Continue to monitor recent improvements

This intersection is ranked the highest in terms of crash severity. Fortunately, as part of the recent Grand Ave. project, a reduction in crashes seems to be occurring. The location's proximity to the Denfeld school and its connection to the Bong Bridge, however, justify continued monitoring.

Recommendations:

- Continue to monitor conditions at this location.

ROADWAYS:

- MSAS 126 (Grand Ave.)
- MSAS 111 (46th Ave.)

JURISDICTIONS:

- City of Duluth

CAPACITY (LOS):

- Grand Ave. = A-B
- 46th Ave. W = A-B

CRASH STATISTICS:

- 5yr total = 23
- 5yr crash rate = 0.68
- Avg. change = -0.28

*** Avg. severity = 3.40**

*** 2005 severity = 4.00**

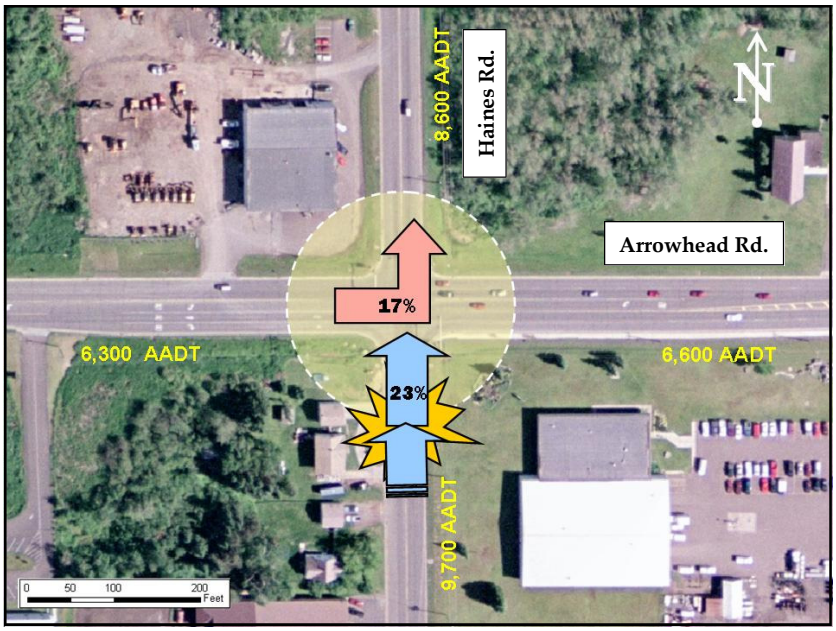
CRASH TYPES:

- Turning = 5 (22%)
- Run-thru = 12 (52%)
- Rear-end = 4 (17%)
- Side-swipe = 1 (4%)
- Unknown = 1 (4%)

DIRECTIONAL INVOLVEMENT:

- NW = 9 (39%)
- SE = 2 (9%)
- NE = 12 (52%)
- SW = 12 (52%)
- Unknown = 3 (13%)

10. Haines Rd. & Arrowhead Rd.



An on-going capacity issue

The MIC's long range plan shows Haines Rd. operating at LOS "C" in 2002, but recent modeling (URS, 2005) shows the intersection operating at LOS "D". The 2005 *Hermantown-Section 13 Circulation Analysis Report* recommends adding L-turn lanes to Haines Rd., lengthening the turn lanes on Arrowhead, and adjusting signal timing. Since the report L-turn lanes have been installed on Haines Rd., but additional treatments may further improve the LOS of this intersection.

Recommendations:

- Adjust signal timing and/or coordination.
- Lengthen L-turn lanes on Arrowhead Rd.

ROADWAYS:

- CSAH 91 (Haines Rd.)
- CSAH 32 (Arrowhead Rd.)

JURISDICTIONS:

- St. Louis County
- City of Duluth
- City of Hermantown

CAPACITY (LOS):

- Haines Rd. = C
- Arrowhead Rd. = A-B

CRASH STATISTICS:

- 5yr total = 27
- *** 5yr crash rate = 1.00**
- Avg. change = -1.16
- Avg. severity = 2.60

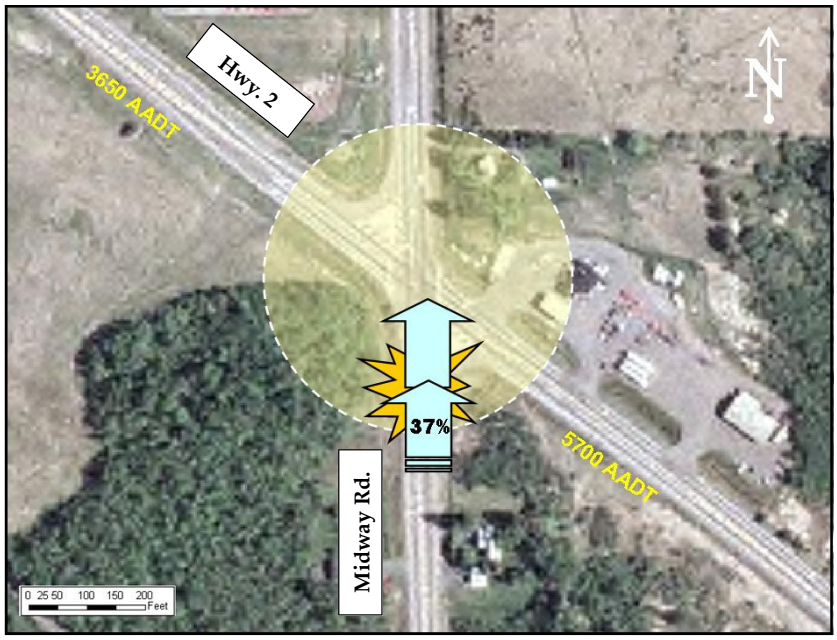
CRASH TYPES:

- Turning = 11 (42%)
- Run-thru = 3 (12%)
- Rear-end = 8 (31%)
- Side-swipe = 3 (12%)
- Off-the-road = 1 (4%)

DIRECTIONAL INVOLVEMENT:

- NW = 11 (41%)
- SE = 7 (26%)
- NE = 9 (33%)
- SW = 6 (22%)
- Unknown = 5 (19%)

11. US Hwy 2 & Midway Rd.



Is this intersection really a problem?

The intersection of Hwy. 2 and Midway Rd. is Signalized, has L-turn lanes and protected L-turn phases. Seemingly, there is little more to be done for this intersection with no apparent congestion or safety issues. Yet, the majority of crashes that have occurred here are rear-end collisions from N-bound vehicles on Midway Rd., hinting that some type of adjustment may be needed.

Recommendations:

- Investigate current signal coordination and continue to monitor.

ROADWAYS:

- USTH 91 (Hwy. 2)
- CSAH 13 (Midway Rd.)

JURISDICTIONS:

- MnDOT District 1
- St. Louis County

CAPACITY (LOS):

- Hwy. 2 = A-B
- Midway Rd. = A-B

CRASH STATISTICS:

- 5yr total = 8
- 5yr crash rate = 0.39
- *** Avg. change = 0.18**
- Avg. severity = 1.90

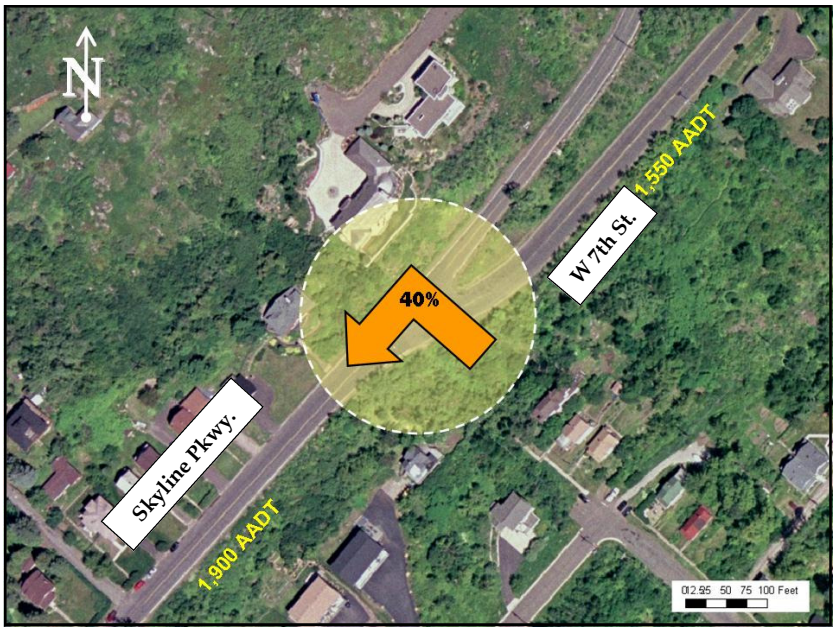
CRASH TYPES:

- Turning = 0 (0%)
- Run-thru = 2 (25%)
- Rear-end = 5 (63%)
- Side-swipe = 1 (12%)

DIRECTIONAL INVOLVEMENT:

- N = 3 (38%)
- S = 1 (13%)
- SE = 2 (18%)
- NW = 2 (18%)

12. Skyline Parkway & W 7th St.



A hidden intersection

Crashes at this location appear to be due to the elevated, acute angle of W 7th's approach, which obscures the view of the upcoming intersection for SW-bound traffic on Skyline Pkwy. Vegetation, further-more, currently masks the stop sign.

Although vehicle traffic is light, Skyline Parkway remains a favorite route for bikers and pedestrians. The rural feel of the road, however, may encourage faster speeds, while narrow shoulders provide pedestrians little buffer from vehicles.

Recommendations:

- Clear vegetation away from stop sign.
- Install sign to warn of "blind" intersection.

ROADWAYS:

- MSAS 113 (Skyline Pkwy.)
- MSAS 127 (W 7th St.)

JURISDICTIONS:

- City of Duluth

CAPACITY (LOS):

- Skyline Pkwy. = A-B
- W 7th St. = A-B

CRASH STATISTICS:

- 5yr total = 10

*** 5yr. crash rate = 2.05**

- Avg. change = -0.39
- Avg. severity = 1.70

*** 2005 severity = 3.00**

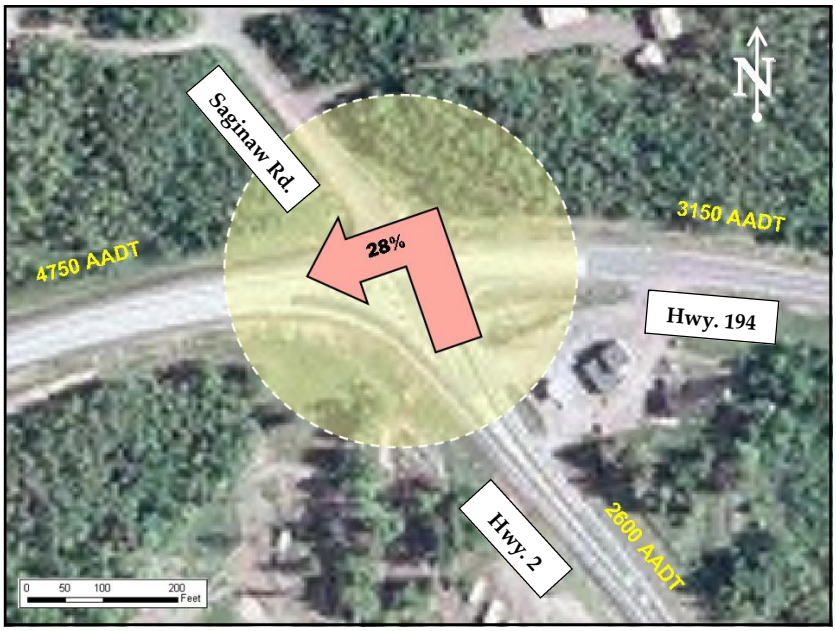
CRASH TYPES:

- Turning = 5 (50%)
- Run-thru = 1 (10%)
- Rear-end = 3 (30%)
- Side-swipe = 1 (10%)
- Pedestrian = 1 (10%)

DIRECTIONAL INVOLVEMENT:

- NE = 2 (20%)
- SW = 6 (60%)
- W = 5 (50%)
- Unknown = 1 (10%)

13. US Hwy 2 & State Hwy 194



Are drivers misjudging gaps?

Since the majority of crashes (61%) at this 2-way stop-controlled intersection are angle crashes involving vehicles traveling north on US Hwy. 2, it appears there's a tendency for drivers to misjudge the distance and/or speeds of oncoming vehicles. Since warning beacons already exist at the intersection, what else can be done to reduce the high average crash rate?

Recommendations:

- Install advance warning signs for W-bound traffic about vehicles entering the intersection up ahead.
- Install ITS warning message to be initiated by vehicles approaching on Hwy. 2.

ROADWAYS:

- USTH 2 (Hwy. 2)
- STH 194 (Hwy. 194)
- CSAH 46 (Saginaw Rd.)

JURISDICTIONS:

- MnDOT District 1
- St. Louis County

CAPACITY (LOS):

- Hwy. 2 = A-B
- Hwy. 194 = A-B
- Saginaw Rd. = A-B

CRASH STATISTICS:

- 5yr total = 18
- *** 5yr. crash rate = 1.81**
- Avg. change = -0.45
- Avg. severity = 1.80

CRASH TYPES:

- Turning = 8 (44%)
- Run-thru = 5 (33%)
- Rear-end = 3 (17%)
- Off-the-road = 3 (17%)

DIRECTIONAL INVOLVEMENT:

- NW = 9 (50%)
- SE = 1 (6%)
- E = 9 (50%)
- W = 9 (50%)
- Unknown = 2 (11%)

Efficiency-focused treatments

Relatively low-cost treatments, such as coordinating the timing of adjacent signals or adding channelization to an intersection, can lead to significant improvements in the flow of traffic. The FHWA states that by merely adjusting signal timing alone communities can achieve cost/benefit ratios of as high as 40:1 (http://ops.fhwa.dot.gov/aboutus/one_pagers/arterial_mgmt.pdf). When deciding which TSM strategies would be best suited for a specific efficiency problem, the larger transportation network should be considered. This is especially true for solutions that extend beyond simply removing a particular bottleneck to actually adding capacity to a roadway. Even simple adjustments to signal timing should be made with consideration of potential effects beyond the intersection or road segment to avoid transferring inefficiencies elsewhere. This inter-connectivity underlines the importance for coordination among jurisdictions when working to identify TSM solutions.

Safety-focused treatments

Although the effects of safety-focused improvements will tend to be more localized than those focused on improving LOS, the results can still be significant. Cities like Detroit, Michigan have realized cost/benefit ratios of 1:15 with crash reductions of 50% at intersections that were re-striped, received L-turn lanes, had all-red phases programmed into their signals (http://ops.fhwa.dot.gov/publications/low_cost_traf/low_cost_traf.pdf). Despite the more localized results of safety related treatments, a system-wide approach is still pertinent. Treatments aimed at improving safety at a location should not only focus on solving the problems identified, but also remain relevant to the function of the facility. For instance, the LOS along a busy arterial with crashes occurring at an uncontrolled intersection, for instance, may not be best served by installing additional signals when upgrading and coordinating the existing signals has not yet been looked at.

Menu of TSM options

A menu of both efficiency-focused and safety-focused treatments can be found in the appendix at the end of this document. The menu consists of tables listing a variety of different actions used to address certain problems. The menu is not an exhaustive list, but is meant to provide a starting point from which ideas for solving certain problems can begin to be developed. Creative or innovative treatments not listed in the menu shouldn't be ruled out as potentially sound solutions.

TSM as an additional tool for area jurisdictions

The MIC's TSM process has been designed with consideration of the "3 C's" (continuing, comprehensive and cooperative) planning process. It is intended to be a continual process that involves regularly updated analyses. It is also intended to be flexible by allowing for the inclusion of additional factors as seen fit. Being that the 2007 TSM analysis was the MIC's first attempt at providing a quantitative evaluation of the network, there is no doubt room for improvement. Input from jurisdictions and area transportation agencies is being sought to determine how the TSM process can be made more relevant for them. MIC staff intends to use this feedback to improve upon the TSM analysis in order to make it both an effective and relevant tool.

Beyond the regularly-run TSM analyses, staff at the MIC is prepared to provide TSM and safety-related information to jurisdictions upon request, extending its usefulness beyond the initial TSM study. **Questions or comments can be directed to Robert Herling at (218) 529-7572 or by email: rherling@ardc.org.**

Appendix: Menu of TSM actions

Table A.1: Actions to address congestion along roadways	
POSSIBLE CAUSE	ACTION
1. Capacity exceeded only at peak hours or during an event	A. Use peak period parking restrictions B. Increase transit service and options (eg. Park & Ride lots) C. Restrict bus and truck traffic during peak hours D. Install reverse-peak lanes E. Introduce high-occupancy vehicle (HOV) lanes F. Install changeable message signs (e.g. ITS units) G. Install ramp metering H. Temporarily close accesses
2. Long queues at intersections or accesses causing bottlenecks	A. Convert a 2-way STOP to a 4-way STOP B. Adjust signal intervals C. Upgrade to actuated signals D. Improve turning radius of curb E. Restripe to add turn lanes F. Stripe in a center L-turn lane G. Construct turn bays H. Install center median to prevent L-turns I. Partially or fully close accesses J. Install a roundabout
3. Facility design restricts capacity	A. Adjust signal intervals along route B. Coordinate signal timing at nearby intersections C. Remove on-street parking D. Restrict or relocate buses and trucks E. Re-stripe narrower lanes to add capacity F. Widen a portion of the roadway at area of bottleneck G. Convert roads into ONE WAY pairs H. Construct turn bays for accesses I. Advertise and incentivise transit and commuting options J. Provide Park & Ride lots

Table A.1 (cont'd): Actions to address congestion along roadways	
POSSIBLE CAUSE	ACTION
4. Stopping buses causing backups	a. Prohibit parking near bus stop b. Stripe in reserved loading zones c. Lengthen loading zones d. Reroute buses to another roadway e. Install bus ports f. Install reserved bus lanes
5. Bus service is hampered by traffic conditions	a. Improve bus stop spacing b. Implement skip stops c. Reroute buses to another roadway d. Install signal "pre-emption" for buses along route e. Install reserved bus lanes f. Install Park & Ride lots g. Increase parking enforcement

Table A.2: Actions to address congestion at intersections	
POSSIBLE CAUSE	ACTION
6. Inadequate traffic control device	a. Convert a 4-way STOP into a 2-way STOP b. Install a traffic signal c. Remove unnecessary signals
7. Inefficient signal timing/phasing	a. Adjust signal intervals phasing b. Provide protected L-turn phase c. Adjust timing at adjacent signals d. Upgrade to actuated signalization
8. Turning vehicles disrupt flow	a. Stripe in or lengthen acceleration lanes b. Construct turning bays c. Provide a wider turning radius d. Add L-turn signals with protected L-turn phase e. Prohibit L-turns with a centerline median f. Prohibit turns with partial or full closure g. Install a roundabout
9. Turning buses or vehicles block lanes	a. Relocate bus stops b. Provide a larger turning radius c. Redirect buses and trucks during peak hours d. Restrict buses and trucks
10. Long queues resulting in backups	a. Adjust signal timing or phasing b. Stripe in or lengthen turn lanes c. Install actuated signalization
11. Driver disorientation	a. Improve signage (more, larger, brighter, etc.) b. Use pavement messages c. Improve lighting d. Add channelization

Table A.3: Actions to address pedestrian and bike crashes	
POSSIBLE CAUSE	ACTION
12. Poor visibility	a. Improve street lighting b. Use brighter, more reflective pavement markings c. Install illuminated strips in ped crossing d. Install crossing signs e. Use larger, more reflective signs f. Install centerline safe-hit ped crossing sign g. Double up signs, post signs overhead h. Install warning beacon on sign i. Remove parking near crossing
13. Restricted sight distance	a. Remove obstructions b. Install advance warning signs c. Install advanced warning beacon d. Use advanced pavement messages e. Reroute bikes and peds to a different location
14. Proper stopping distance unclear	a. Install or improve crosswalk b. Install advanced stop bars before crossing
15. Mid-block crossings/ 2-way intersections	a. Provide a mid-block crosswalk with YIELD signs b. Install ped crossing signs and warning beacons c. Install centerline safe-hit ped crossing sign d. Prohibit ped crossings with a barrier e. Install yield signs or convert to a 4-ways stop
16. Severe curves	a. Install or improve edge line b. Install safe-hit edge line delineators c. Widen paved shoulder d. Provide sidewalk or segregated bike trail
17. Excessive speeds	a. Reduce posted speeds, use speed trailer b. Increase traffic enforcement c. Provide wider shoulders or designated bike lanes d. Provide sidewalk or segregated bike trail e. Install speed hump

Table A.3 (cont'd): Actions to address pedestrian and bike crashes	
POSSIBLE CAUSE	ACTION
18. Excessive speeds (cont'd)	a. Install bulb outs or pedestrian island b. Install traffic circle
19. Unrestricted right turns	a. Install bike lanes with merging areas before intersection b. Install bike paths that route cyclists away from turn lane
20. Signal intervals	a. Adjust signal timing or phasing b. Provide a protected pedestrian interval c. Mark signal loops on pavement for cyclists d. Install ped crossing signals e. Install countdown signals f. Install ped detectors g. Install bulb-outs or pedestrian islands

Table A.4: Actions to address head-on, side-swipe, or off-the-road crashes	
POSSIBLE CAUSE	ACTION
21. Restricted sight distance	a. Stripe a NO PASSING zone b. Install NO PASSING ZONE signs c. Install advance warning signs; advised speed d. Remove upcoming hazards restricted from view e. Reduce obstructions on the inside of curves f. Install rumble stripes g. Lower roadbed on hill crests
22. Poor visibility	a. Improve lighting b. Use larger, more reflective signs c. Delineate trees and poles with reflective tape d. Use larger, brighter, more reflective pavement markings e. Install safe-hit edge delineators f. Install warning beacon
23. Severe curves	a. Post curve warnings; advised speeds b. Install chevron signs; paint chevrons in roadway c. Remove or relocate roadside hazards d. Widen or pave shoulders e. Install design-appropriate guardrails f. Groove pavement/improve drainage g. Flatten roadway or provide proper banking
24. Narrow lanes	a. Mark center lines or improve pavement markings b. Eliminate parking c. Widen lanes or pave shoulders d. Install rumble stripes e. Convert to ONE WAY
25. Excessive speeds	a. Install more speed limit signs along route b. Reduce posted speed limit c. Use speed trailer or pole-mounted radar d. Use pavement markings/Install speed bumps e. Install median, bulb outs, chicanes to calm traffic f. Increase speed enforcement

Table A.5: Actions to address angle crashes at unsignalized intersections	
POSSIBLE CAUSE	ACTION
26. Restricted sight distance	a. Remove obstructions from sight triangle b. Eliminate parking near intersection c. Reposition signs d. Install advance warning signs or signals e. Install YIELD signs f. Change from a 2-way to a 4-way stop g. Signalize intersection
27. Poor visibility of STOP/YEILD signs	a. Remove sign sight obstructions b. Add/improve lighting at intersection c. Install advance warning signs or pavement markings d. Reposition signs (at-ground or overhead) e. Place flags atop signs f. Install larger, brighter, more reflective signs g. Double-up signs (each side of roadway) h. Install transverse rumble strip i. Install warning beacon
28. Proper stopping position is unclear	a. Add stop bars or crosswalks b. Add or improve lighting at intersection
29. Slippery surface	a. Post warning signs b. Groove pavement c. Improve drainage
30. Excessive speeds	a. Install more speed limit signs along the route b. Reduce posted speed limit c. Use a speed trailer or post-mounted radar d. Increase speed enforcement e. Increase on-street parking to calm traffic f. Medians, bulb outs, chicanes along route (traffic calming) g. Install traffic circle h. Install center median to prohibit thru movements i. Relocate or close accesses near intersection

Table A.6: Actions to address angle crashes at signalized intersections

POSSIBLE CAUSE	ACTION
31. Restricted sight distance	a. Remove obstructions from sight triangle b. Eliminate parking near intersection c. Close or relocate accesses near intersection
32. Poor visibility of traffic signal	a. Use advance warning signs/advance flasher b. Add back plates/install signal visors c. Increase lens size d. Convert from bulbs to LEDs e. Relocate signal overhead f. Add more signal heads (per lane)
33. Inadequate signal change interval	a. Increase Yellow change interview b. Add all-red clearance interval c. Increase all-red clearance interval
34. Proper stopping position unclear	a. Add stop bars or crosswalks b. Add or improve signal lighting
35. Slippery surface	a. Post advance warning signs b. Groove pavement c. Improve drainage
36. Excessive speeds	a. Install more speed limit signs along the route b. Reduce posted speed limit c. Use a speed trailer or pole-mounted radar d. Increase speed enforcement e. Increase on-street parking to calm traffic f. Add median, bulb outs, chicanes along route g. Install center median to prohibit thru movements h. Relocate or close accesses near intersection
37. Unexpected/unnecessary stopping	a. Reprogram signal b. Provide signal progression c. Install signal actuation

Table A.7: Actions to address rear-end crashes at unsignalized intersections	
POSSIBLE CAUSE	ACTION
38. Crossing pedestrians	a. Add stop bars or crosswalks b. Post ped crossings, advance warning sings c. Paint advance pavement message d. Add or improve intersection lighting e. Reroute pedestrians to a safer crossing via barriers
39. Stopping in through thru lanes	a. Add exclusive turn lanes b. Lengthen turn lanes c. Add two-way center turn lanes d. Increase curb or edge of pavement radius e. Widen approaches to handle turn lanes f. Prohibit turns with partial closures or center medians
40. Unexpected slowing and lane changing	a. Install guide signs or larger, brighter signs b. Add or improve pavement markings c. Add or lengthen acceleration lanes d. Improve geometry
41. Inadequate gaps for turning and accelerating	a. Change from a 2-way to a 4-way stop b. Add or lengthen acceleration lanes c. Signalize intersection
42. Poor visibility of STOP/YIELD signs	a. Remove sign sight obstructions b. Add or improve lighting at intersection c. Install advance warning signs or pavement markings d. Reposition signs (at-ground or overhead) e. Place flags atop of signs f. Install larger, brighter, more reflective signs g. Double-up signs (each side of roadway) h. Install transverse rumble strip i. Install a warning beacon
43. Narrow lanes	a. Eliminate parking b. Restripe for wider lanes c. Increase edge of pavement

Table A.7 (cont'd): Actions to address rear-end crashes at unsignalized intersections	
POSSIBLE CAUSE	ACTION
44. Excessive speeds	a. Add more speed limit signs along route b. Reduce posted speed limit c. Put flags atop signs d. Use speed trailer or pole-mounted radar e. Increase enforcement f. Install median, bulb outs, chicanes along route
45. Slippery surface	a. Post advance warning signs b. Groove pavement c. Improve drainage

Table A.8: Actions to address rear-end crashes at signalized intersections	
POSSIBLE CAUSE	ACTION
46. Crossing pedestrians	a. Add stop bars crosswalks b. Post ped crossing sings, advance warning sings c. Paint advance pavement message d. Add or improve intersection lighting e. Install ped crossing signals f. Reroute pedestrians to a safer crossing via barriers
47. Unexpected/unnecessary stops due to signal	a. Revise signal phasing sequence b. Retime signal or upgrade signal controller c. Better coordinate other nearby signals d. Install signal actuation e. Remove unwarranted signal
48. Unexpected slowing and lane changing	a. Install guide signs/larger, brighter signs b. Add or improve pavement markings c. Add or lengthen acceleration lanes d. Improve geometry
49. Turning vehicles slowing or in thru lanes	a. Mark exclusive turn lanes b. Lengthen turn lanes c. Install two-way center turn lanes d. Increase curb radius or edge of pavement e. Widen approach to handle turn lanes f. Add pre-timed, protected L-turn signals g. Install signal actuation h. Install dual L-turn lanes, signs & signals i. Provide split phasing j. Prohibit turns with partial closure/median
50. Unsafe right turns on red	a. Reduce sight obstructions b. Add R-turn lane channelization c. Provide R-turn overlap (green arrow) d. Prohibit R-turns on red

Table A.8 (cont'd): Actions to address rear-end crashes at signalized intersections	
POSSIBLE CAUSE	ACTION
51. Excessive speeds	a. Add more speed limit signs along route b. Reduce posted speed limit c. Put flags atop signs d. Use speed trailer or pole-mounted radar e. Increase enforcement f. Install median, bulb outs, chicanes along route
52. Poor visibility of traffic signal	a. Remove signal sight obstructions b. Post advance warning signs or advance flasher c. Add back plates or install signal visors d. Increase lens size e. Replace bulbs with LED's f. Relocate signal overhead g. Add more signal heads (per lane)
53. Narrow lanes	a. Eliminate parking b. Restripe for wider lanes c. Increase edge of pavement
54. Slippery surface	a. Post advance warning signs b. Groove pavement c. Improve drainage