Minnesota Department of Transportation

# Minnesota's I-35 Planning Study

## SAFETY DATA CASE STUDY

FHWA-SA-21-077

Federal Highway Administration Office of Safety

Roadway Safety Data Program

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U.S. Department of Transportation
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# Acronyms

| Acronym | Description |
|---|---|
| **A** | suspected serious injury |
| **AADT** | annual average daily traffic |
| **AASHTO** | American Association of State Highway and Transportation Officials |
| **B** | suspected minor injury |
| **C** | possible injury |
| **CSAH** | County State-Aid Highway |
| **FA** | fatal and incapacitating injury |
| **FHWA** | Federal Highway Administration |
| **HSM** | Highway Safety Manual |
| **ISATe** | Enhanced Interchange Safety Analysis Tool |
| **ITS** | intelligent transportation system |
| **K** | fatality |
| **MnCMAT** | Minnesota Crash Mapping Analysis Tool |
| **MnDOT** | Minnesota Department of Transportation |
| **mph** | miles per hour |
| **O** | property damage only |
| **SEE** | Social, Environmental, and Economic |
| **TH** | Trunk Highway |
| **VMT** | vehicle miles traveled |

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# Executive Summary

This case study describes the Minnesota Department of Transportation's (MnDOT's) use of the Enhanced Interchange Safety Analysis Tool (ISATe) as a part of a planning study for an approximately 7-mile segment of Interstate 35 (I-35) in Carlton County. I-35 carries commuter and recreational traffic, and it is a main freight corridor for the area. Most of the bridges in the study area were 45 to 55 years old, and many of the bridges and pavement sections along the corridor were reaching the end of their service life and would require rehabilitation or replacement. This study identified safety, operational, and mobility needs along the corridor and developed alternatives which were then coordinated with upcoming infrastructure replacement projects. The I-35 planning study is an example of incorporating quantitative safety analysis as part of a comprehensive review process. MnDOT's work to obtain stakeholder feedback and analyze existing safety conditions allowed the project team to establish safety as a project need. Additional evaluation of specific needs led MnDOT to develop a suite of alternatives that balanced environmental sensitivity with access and safety. ISATe provided the technical capacity to assess the study area's baseline conditions based on existing geometrics and traffic, and estimate predicted crashes based on forecast conditions. The benefit-cost analysis provided further confidence that MnDOT's alternatives will be cost effective and will provide a high level of benefit to users of the I-35 corridor.

# Introduction

The Transportation Research Board's Safety Performance and Analysis (ACS20) User Liaison Subcommittee has an on-going initiative focused on practical application of the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual (HSM) (i.e., "using the HSM in the real world"). The Federal Highway Administration (FHWA) also administers the HSM Implementation Pooled Fund, which includes 22 States focused on projects to help further HSM implementation. Development of HSM case studies will assist practitioners in performing data-driven safety analysis using the advanced methods described in the HSM. The primary purpose of this and other HSM case studies is to highlight noteworthy applications of HSM methods, focus on common challenges, and feature agencies that overcame those challenges. These case studies serve as a source of lessons learned and noteworthy practices to help guide practitioners applying the HSM.

## Background

This case study presents a planning-level safety analysis published by the Minnesota Department of Transportation (MnDOT) in 2017. MnDOT used the Enhanced Interchange Safety Analysis Tool (ISATe) as a part of a planning study for an approximately 7-mile segment of Interstate 35 (I-35) in Carlton County, MN (figure 1). There are 4 interchanges and 17 bridges in the study area, which carries commuter and recreational traffic and serves as a freight corridor. Many of the bridges and segments of pavement along the corridor are reaching the end of their service life. This study identified safety, operational, and mobility needs along the corridor which can be implemented in coordination with upcoming infrastructure replacement projects. The planning study included several components:

- Traffic operations analysis.
- Safety analysis.
- Traffic forecast.
- Social, environmental, and economic (SEE) assessment.
- Existing infrastructure evaluation.
- Corridor design review.

Although the I-35 Planning Study used these metrics to inform the future design and function of the corridor, this case study specifically focuses on the relevant components of MnDOT's safety analysis.

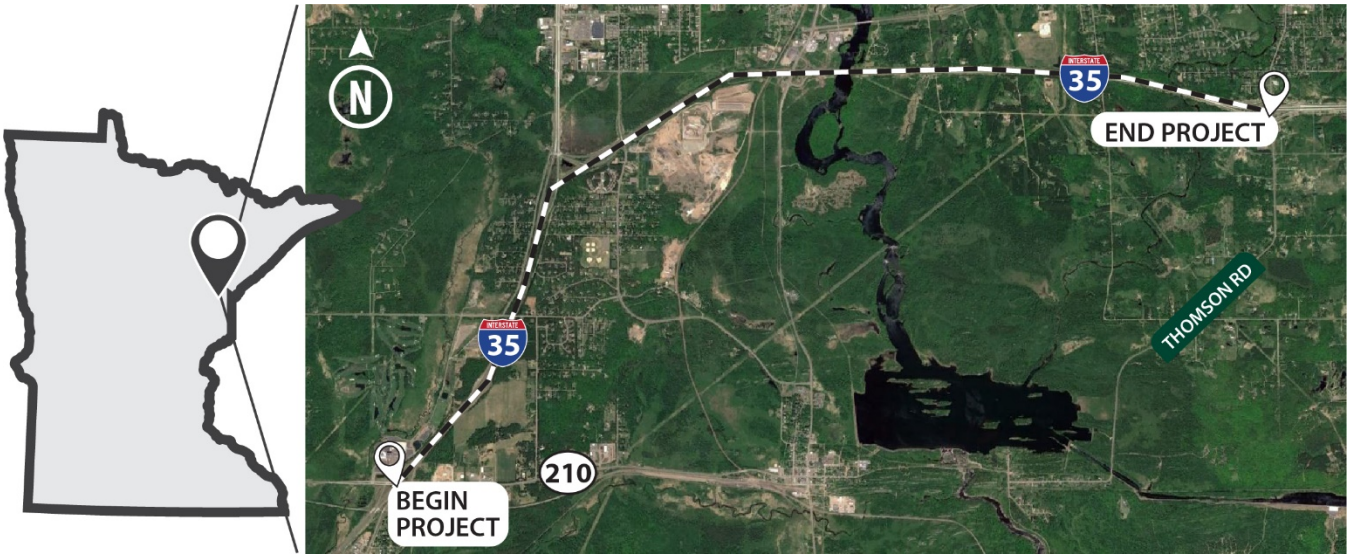


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Figure 1. Graphic. I-35 project location.

## Purpose and Need

I-35 carries commuter and recreational traffic, and it is a primary freight corridor for the area. Most of the bridges in the study area were 45 to 55 years old, and many of the bridges and pavement sections along the corridor were reaching the end of their service life. These would require rehabilitation or replacement. This study identified safety, operational, and mobility needs along the corridor and developed alternatives which were then coordinated with upcoming infrastructure replacement projects. The I-35 Planning Study was divided into three phases (figure 2):

- Phase I – Purpose and Need/Issue Development.
- Phase II – Development and Alternative Evaluation.
- Phase III – Recommendations and Implementation Plan.

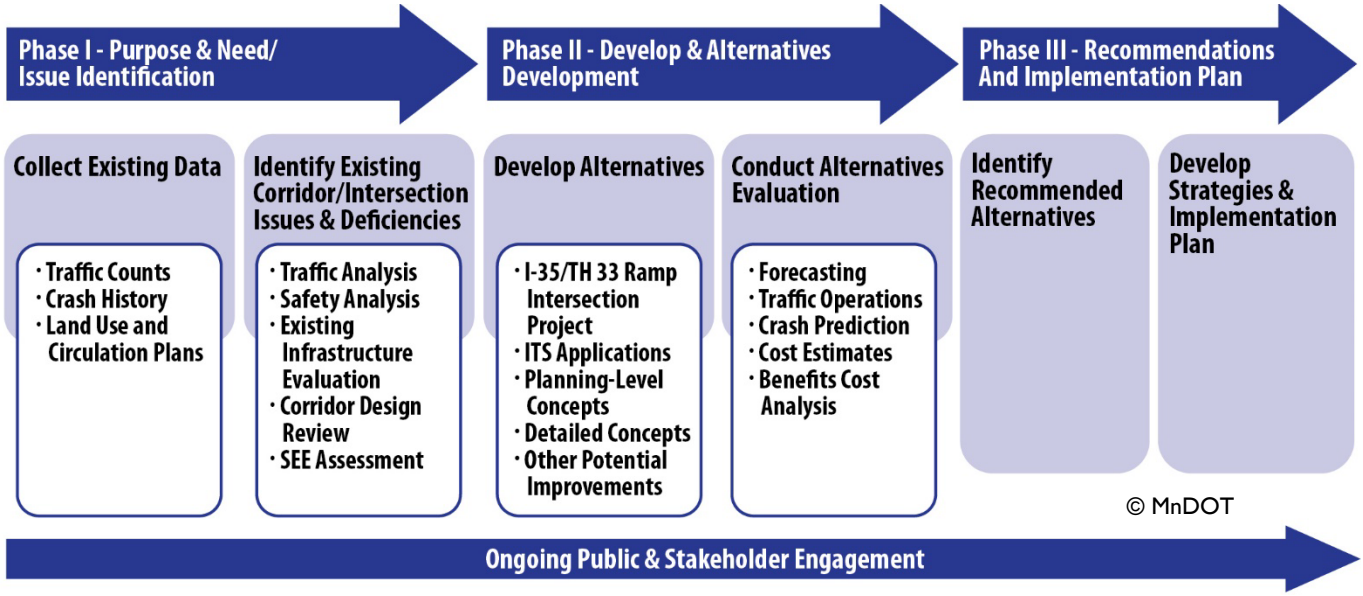


Figure 2. Graphic. I-35 study process.

MnDOT evaluated existing safety conditions as part of a broad Phase I, Purpose and Need Identification process. For Phase II, Alternatives Development, the project team used ISATe to compare the safety performance of the existing conditions and alternatives and determine how each would impact safety performance. The project team also used ISATe results to perform a benefit-cost analysis to determine if the alternatives are economically justified. The project team then identified recommended alternatives in Phase III, Recommendations and Implementation Plan, and prioritized the projects.

## Project Description

- **Sponsoring agency:** MnDOT.
- **Project location:** Carlton County, MN.
- **Project bounds and length of project:** 7 mi along I-35 from 2 mi south of the I-35/ Trunk Highway (TH) 210 interchange to the I-35/County State-Aid Highway (CSAH) 61 interchange.
- **Facility type(s):** 4-lane, divided Interstate highway.
- **Area type:** Rural.
- **Project status (as of October 2021):** Construction of the roundabout at I-35 and TH 33 completed in 2018.

# Safety Performance Analysis

This section provides an overview of the safety analysis methods, proposed alternatives, and final results.

## Existing Conditions Safety Analysis

The I-35 Planning Study obtained information on existing safety concerns and future needs from several sources, including public engagement meetings and historical crash analysis. The project team obtained the most recent five years of crash data available at the time the analysis (2011 through 2015) from the Minnesota Crash Mapping Analysis Tool (MnCMAT).[1] The I-35 study corridor began two miles south of the I-35/TH 210 interchange and extended to the I-35/CSAH 61 interchange. The I-35 analysis investigated freeway segments and interchanges separately.

The project team segmented mainline crash data into the following sections for analysis:

- Approximately 2 mi south of TH 210 to the TH 210 interchange.
- TH 210 interchange to the TH 33 interchange.
- TH 33 interchange to the TH 45 interchange.
- TH 45 interchange to the CSAH 1 interchange.
- CSAH 1 interchange to the CSAH 61 interchange.

For the safety analysis, the project team compared the historical crash data with the statewide average crash rate and calculated the critical crash rate (i.e., comparison of actual crash rate to expected crash rate) and crash rate index (i.e., the calculated crash rate divided by the critical crash rate at each location) to identify initial safety concerns. A crash rate index greater than one indicates that a location has a crash rate higher than the critical crash rate and represents a potential safety need. Tables 1 and 2 display the historical crash data for the segments along the I-35 corridor by total crashes and fatal (K) and suspected serious injury (A)[2] crashes.

[1] MnCMAT has since been replaced by the MnCMAT2 system.
[2] MnDOT defined A injury crashes as "incapacitating injury" at the time of the study.

**Table 1. Historical total crash data by segment for the I-35 corridor (2011-2015).**

| Start of Segment | End of Segment | Segment Length (mi) | Annual Average Daily Traffic (AADT) | Total Crash Frequency | Calculated Crash Rate[1] | Critical Crash Rate | Crash Rate Index[2] |
|---|---|---|---|---|---|---|---|
| 2 miles south of TH 210 | TH 210 | 2.00 | 16,400 | 31 | 0.52 | 0.68 | 0.76 |
| TH 210 | TH 33 | 1.47 | 26,000 | 45 | 0.65 | 0.66 | 0.97 |
| TH 33 | TH 45 | 1.07 | 17,600 | 21 | 0.61 | 0.76 | 0.80 |
| TH 45 | CSAH 1 | 2.26 | 27,000 | 64 | 0.57 | 0.62 | 0.93 |
| CSAH 1 | CSAH 61 | 2.5 | 27,000 | 61 | 0.49 | 0.61 | 0.81 |
| **Total** | **N/A** | **N/A** | **N/A** | **222** | **N/A** | **N/A** | **N/A** |

[1] Crashes per million vehicle miles traveled (VMT).
[2] Crash rate divided by the critical crash rate.

**Table 2. Historical KA crash data by segment for the I-35 corridor (2011-2015).**

| Start of Segment | End of Segment | Segment Length (mi) | Annual Average Daily Traffic (AADT) | KA Crash Frequency | Calculated Crash Rate[1] | Critical Crash Rate | Crash Rate Index[2] |
|---|---|---|---|---|---|---|---|
| 2 miles south of TH 210 | TH 210 | 2.00 | 16,400 | 2 | 3.34 | 0.79 | 4.22 |
| TH 210 | TH 33 | 1.47 | 26,000 | 1 | 1.44 | 0.78 | 1.84 |
| TH 33 | TH 45 | 1.07 | 17,600 | 1 | 2.90 | 0.84 | 3.45 |
| TH 45 | CSAH 1 | 2.26 | 27,000 | 2 | 1.79 | 0.75 | 2.38 |
| CSAH 1 | CSAH 61 | 2.5 | 27,000 | 0 | 0.00 | 0.75 | 0.00 |
| **Total** | **N/A** | **N/A** | **N/A** | **6** | **N/A** | **N/A** | **N/A** |

[1] Crashes per 100 million VMT.
[2] Crash rate divided by the critical crash rate.

The project team also assigned crashes to the following interchanges:

- I-35 and TH 210
- I-35 and TH 33
- I-35 and TH 45
- I-35 and CSAH 1

Since there were no standard crash rates for interchanges, the project team developed average crash rates using interchanges in out-state Minnesota (out-state referring to MnDOT Districts 1 through 4 and 6 through 8; i.e., those outside of the Minneapolis/St. Paul area Metro District). Metro District interchanges are more urban with higher traffic volumes, and these locations did not suit the I-35 context. Table 3 displays the historical crash data for the interchanges along the I-35 corridor by total crashes and fatal and suspected serious injury crashes. Four out of the five segments and three out of four interchanges had a KA injury crash rate greater than the statewide average.

**Table 3. Historical crash data by interchange for the I-35 corridor (2011-2015).**

| Location Description | Interchange Type | Total Crash Frequency | Total Crash Rate[1] | Critical Crash Rate[2] | Total Crash Rate Index[3] | KA Crash Frequency | KA Crash Rate[4] | Critical Crash Rate[2] | KA Crash Rate Index[3] |
|---|---|---|---|---|---|---|---|---|---|
| TH 210/W of Carlton County | Diamond | 34 | 0.64 | 1.03 | 0.63 | 1 | 1.90 | 1.21 | 1.57 |
| TH 33/Cloquet | Full Directional | 72 | 1.09 | 1.00 | 1.09 | 5 | 7.55 | 1.19 | 6.36 |
| TH 45/Scanlon | Folded Diamond | 54 | 1.01 | 1.03 | 0.98 | 0 | 0.00 | 1.21 | 0.00 |
| CSAH 1 Near Esko | Diamond | 22 | 0.41 | 1.03 | 0.40 | 2 | 3.73 | 1.21 | 3.09 |
| **Total** | **N/A** | **182** | **N/A** | **N/A** | **N/A** | **8** | **N/A** | **N/A** | **N/A** |

[1] Crashes per million entering vehicles.
[2] Average for the specified interchange types in out-state Minnesota.
[3] Crash rate divided by the critical crash rate.
[4] Crashes per 100 million entering vehicles.

## Crash Prediction Analysis and Results

ISATe is a Microsoft Excel™-based spreadsheet crash prediction tool that automates the methods in HSM Chapters 18 and 19. These pertain to freeways and ramps and quantify the safety implications of different freeway design elements based on geometric design and the average crash frequency. The project team used ISATe to analyze baseline conditions, as well as future alternatives, including a future year (2040) "No Build" alternative and alternatives with safety improvements.

### Baseline Conditions

The ISATe crash analysis for the baseline conditions predicted crashes on all mainline segments and ramps between TH 210 and TH 45 based on existing road geometry, traffic control, and traffic volumes. Table 4 compares the historical average observed crashes and the uncalibrated predicted crashes from ISATe. Results indicate that the total predicted crashes (46.9) are similar to the observed crashes (48.6). This indicated that ISATe was closely matching observed conditions, with a difference of less than 5 percent between predicted and observed crashes.

**Table 4. Comparison of ISATe predicted crashes and observed crashes by crash severity – existing conditions.**

| Crash Severity | Average Observed Crashes (crashes/year) | ISATe Predicted Crashes (crashes/year) |
|---|---|---|
| Fatal | 0.2 | 0.6 |
| Suspected Serious Injury | 1.6 | 1.6 |
| Suspected Minor Injury (B) | 5.0 | 6.9 |
| Possible Injury (C) | 9.0 | 9.2 |
| Property Damage Only (O) | 32.8 | 28.6 |
| **Total** | **48.6** | **46.9** |

### Year 2040 No Build Safety Analysis

Using forecasted traffic volumes for the year 2040, the project team performed an ISATe safety analysis for a No Build scenario with no other changes to the existing geometric and traffic control conditions. The traffic forecasts assumed a 1.5-percent growth in annual volumes. Table 5 displays the predicted crashes for the No Build alternative and the existing conditions. The results indicate that crashes are expected to increase in the future due to the traffic volume growth.

**Table 5. Comparison of ISATe predicted crashes for the existing conditions and No Build alternative.**

| Crash Severity | Predicted Crashes for Existing Conditions (crashes/year) | Predicted Crashes for No Build Alternative (2040; crashes/year) |
|---|---|---|
| Fatal | 0.6 | 0.8 |
| Suspected Serious Injury | 1.6 | 2.0 |
| Suspected Minor Injury | 6.9 | 9.0 |
| Possible Injury | 9.2 | 12.5 |
| Property Damage Only | 28.6 | 39.0 |
| **Total** | **46.9** | **63.2** |

### Alternatives Safety Analysis

The I-35 planning study conducted a comprehensive review of existing safety, mobility, and environmental concerns along the corridor. MnDOT developed planning-level concepts for the corridor to improve safety and mobility based on:

- An existing traffic operations analysis.
- An existing safety analysis and SEE assessment.
- An existing infrastructure evaluation.
- A corridor design review to identify corridor issues and deficiencies.

Environmental review and stakeholder input revealed that the interchanges at TH 33 and TH 45 needed additional design evaluation to address access and safety concerns for the corridor as a whole.

The concepts for the I-35 and TH 33 interchange included:

- Concept A: Roundabout.
- Concept B: Split Diamond.
- Concept C: Split Diamond North Frontage Only.
- Concept D: Split Diamond South Frontage Only.
- Concept E: Tight Diamond.
- Concept F: Diverging Diamond.

The planning level concepts for the I-35 and TH 45 interchange included:

- Concept A: Wider TH 45 Bridges.
- Concept B: Four Loops Only.
- Concept C: Folded Diamond West.
- Concept D: Bridge Braid Ramps.
- Concept E: Tight Diamond.
- Concept F: Wider TH 45 Bridges with Modified Ramps and Loops.

MnDOT reviewed each alternative for disqualifying flaws and considered right of way and environmental impacts in addition to potential safety and access benefits. The project team and project stakeholders narrowed the preferred list of alternatives to five planning level concepts for detailed traffic and safety analyses. These concepts included:

**TH 33 Interchange**

- Concept A: Single Roundabout (figure 3).
- Concept B: Split Diamond with Collector Distributor (figure 4).
- Concept D: Split Diamond with Eastbound Collector Distributor (figure 5).


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Figure 3. Graphic. Concept A Roundabout.

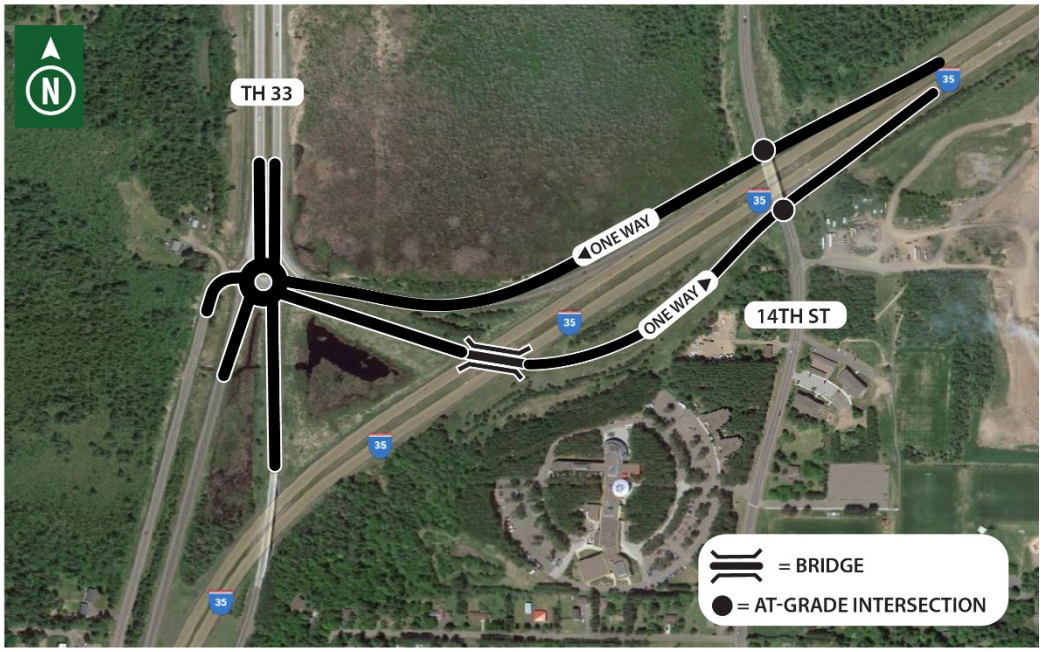


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Figure 4. Graphic. Concept B Split Diamond with Collector Distributor.

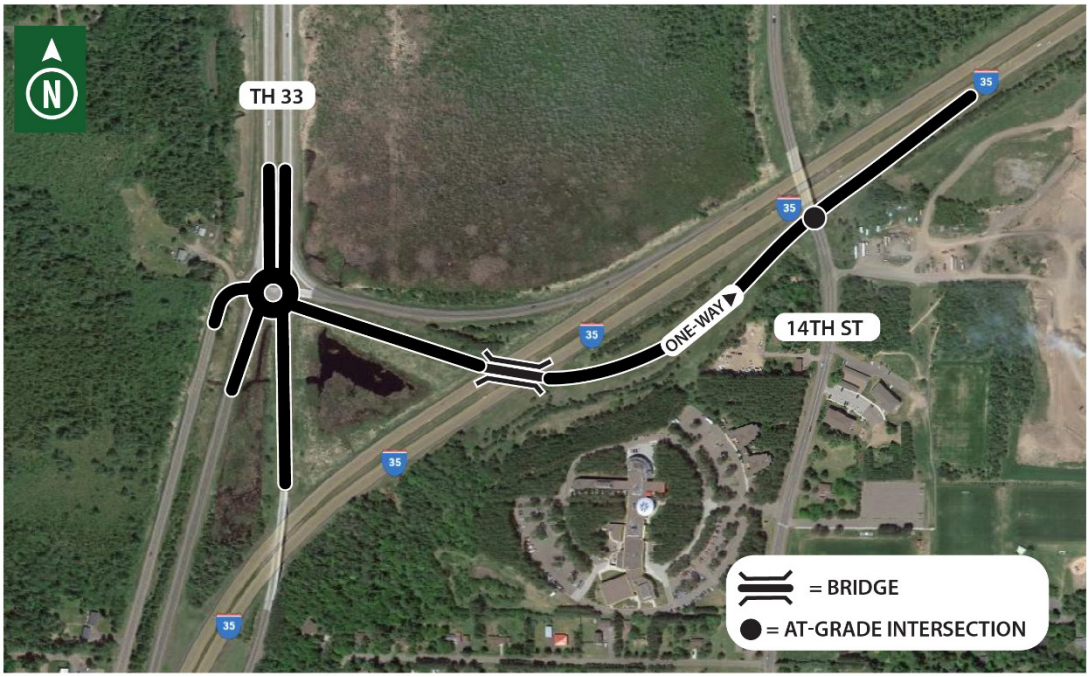


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Figure 5. Graphic. Concept D Split Diamond with Eastbound Collector Distributor.

**TH 45 Interchange**

- Concept A: Wider Bridges (figure 6).
- Concept F: Wider Bridges with Modified Ramps and Loops (figure 7).

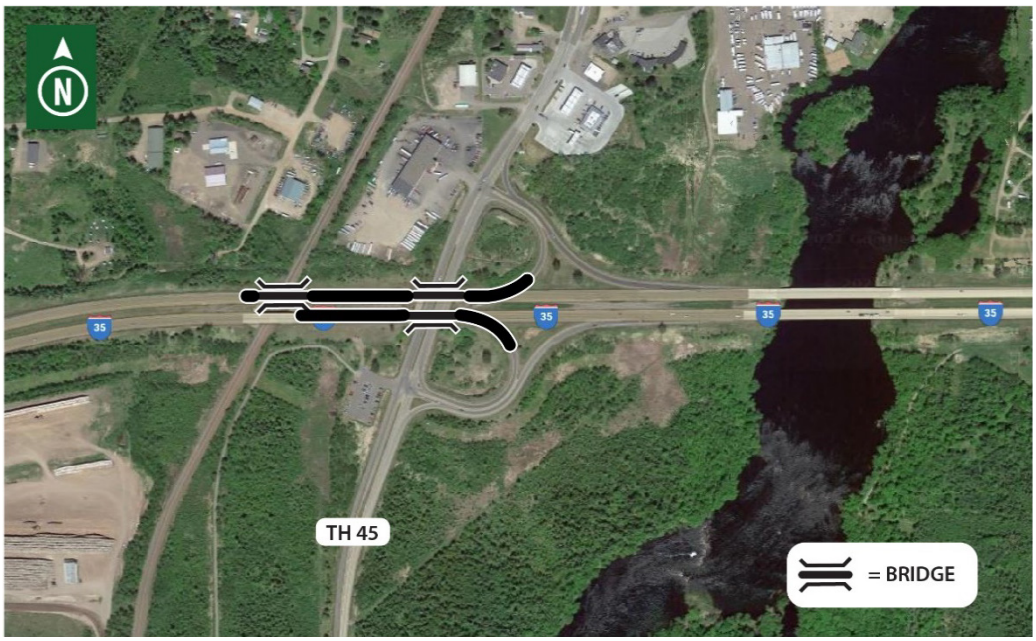


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Figure 6. Graphic. Concept A Wider Bridges.

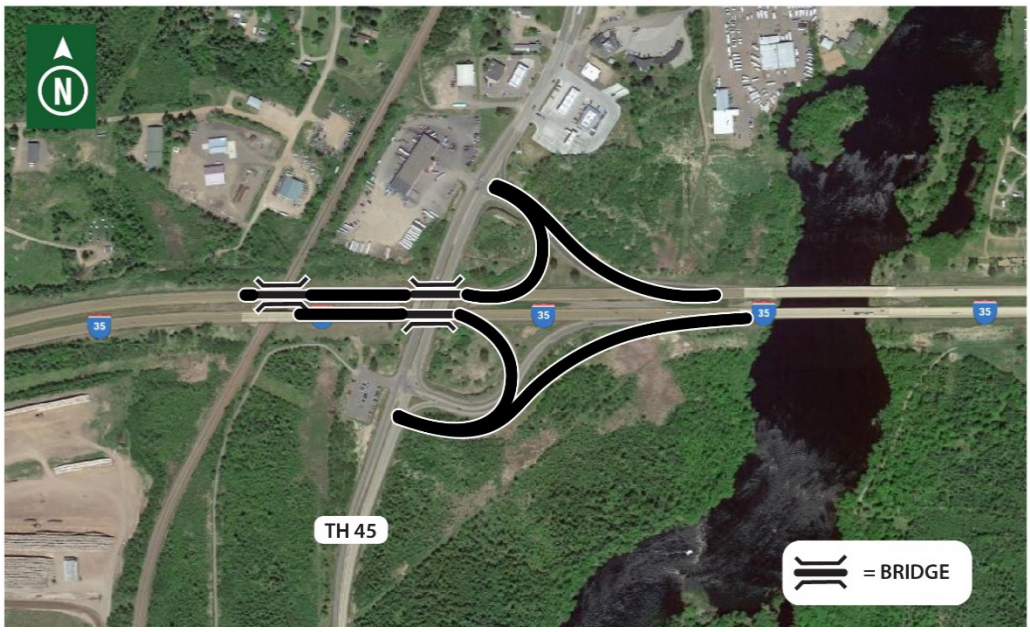


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Figure 7. Graphic. Concept F Wider Bridges with Modified Ramps and Loops.

The project team used ISATe to perform a safety analysis for each of the five concepts using the proposed geometric changes for TH 33 and TH 45. TH 33 Concepts B and D are expected to divert traffic onto I-35 due to the additional access to the freeway. As a result, the project team forecasted traffic on local access roads to account for the route diversion. The project team analyzed both the change in crashes on the local system as well as the freeway to account for the additional traffic accessing I-35.

Table 6 displays the predicted crashes from ISATe for the No Build scenario and four of the concepts. TH 33 Concept A was not included in the analysis since ISATe cannot analyze roundabouts, and a roundabout at that terminal is included in all alternatives. MnDOT noted that since all alternatives included this design, excluding it from ISATe would not bias the comparison.

**Table 6. Predicted crashes per year for the No Build scenario and alternatives.**

| Scenario | System | K | A | B | C | O | Total |
|---|---|---|---|---|---|---|---|
| No Build | Freeway | 0.8 | 2.0 | 9.0 | 12.5 | 39.0 | 63.2 |
| | Change on Local System | - | - | - | - | - | - |
| | **Total** | **0.8** | **2.0** | **9.0** | **12.5** | **39.0** | **63.2** |
| TH 33 Concept B (Split Diamond with Collector Distributor) | Freeway | 0.8 | 2.1 | 9.1 | 12.7 | 40.3 | 65.0 |
| | Change on Local System | -0.06 | -0.11 | -0.61 | -1.22 | -3.60 | -5.61 |
| | **Total** | **0.7** | **2.0** | **8.5** | **11.5** | **36.7** | **59.4** |
| TH 33 Concept D (Split Diamond with Eastbound Collector Distributor) | Freeway | 0.8 | 2.1 | 9.1 | 12.6 | 39.8 | 64.3 |
| | Change on Local System | -0.05 | -0.09 | -0.50 | -1.05 | -3.12 | -4.82 |
| | **Total** | **0.7** | **2.0** | **8.6** | **11.6** | **36.7** | **59.5** |
| TH 45 Concept A (Widen TH 45 Bridges) | Freeway | 0.7 | 2.0 | 8.7 | 12.2 | 38.2 | 61.8 |
| | Change on Local System | - | - | - | - | - | - |
| | **Total** | **0.7** | **2.0** | **8.7** | **12.2** | **38.2** | **61.8** |
| TH 45 Concept F (Widen TH 45 Bridges with Modified Ramps and Loops) | Freeway | 0.7 | 1.9 | 8.3 | 11.3 | 37.2 | 59.4 |
| | Change on Local System | - | - | - | - | - | - |
| | **Total** | **0.7** | **1.9** | **8.3** | **11.3** | **37.2** | **59.4** |

The results indicate that total crashes are expected to decrease for all concepts (TH 33 Concepts B and D and TH 45 Concepts A and F) when compared to the No Build alternative, when considering the change in crashes on both the freeway and local system. For TH 33 Concepts B and D, total crashes are expected to increase on the freeway, while crashes are expected to decrease on the local system due to traffic diverting from the local system to the freeway. However, when considering the change in crashes on both the freeway and local system, TH 33 Concepts B and D experience a total expected crash reduction compared to the No Build scenario.

## Documentation and Use of Analysis Results

Using the aforementioned safety analysis, the project team performed a benefit-cost analysis using cost estimates for each concept (table 7). Crash costs reflect MnDOT's 2016 statewide estimates for each crash severity level (i.e., what was available at the time of the study). Benefits included travel time and delay (e.g., vehicle hours traveled), operations costs (e.g., VMT), and crashes reduced, while the costs include initial capital costs (separated by component categories and service life), operation and maintenance costs, and remaining capital value (i.e., the value of the improvement beyond the 20-year study period). Examples of remaining capital value included right of way acquisition, grading, drainage, and utility relocation. The benefit-cost analysis determined that all design concepts result in a benefit-cost ratio greater than 1.0, indicating the improvements are economically justified. TH 33 Concepts B and D result in the highest benefit-cost ratios, as well as the largest gross benefit.

**Table 7. Benefit-cost analysis results for each concept.**

| | TH 33 Concept B (Split Diamond with Collector Distributor) | TH 33 Concept D (Split Diamond with Eastbound Collector Distributor) | TH 45 Concept A (Widen TH 45 Bridges) | TH 45 Concept F (Widen TH 45 Bridges with Modified Ramps and Loops) |
|---|---|---|---|---|
| Benefits | $46.9 million | $35.1 million | $5.0 million | $14.6 million |
| Costs | $8.0 million | $4.6 million | $3.6 million | $9.2 million |
| Benefit-cost ratio | 5.9 | 7.6 | 1.4 | 1.6 |

In addition to quantitative safety analysis, the I-35 planning study documented additional recommended improvements which were developed in coordination with stakeholders and the public. These forums included stakeholder workshops, a public open house, a booth at a day event on the Fond du Lac Reservation, and online engagement (social media and study webpage). Based on the study process, evaluation, and coordination with stakeholders and the public, MnDOT developed a recommended list of improvements. MnDOT prioritized these into three groups to be programed and completed as funding becomes available.

The first group of projects include:

- Clearing and grubbing.
- Truck rollover warning sign at TH 45.
- CSAH 1 stop sign and stop bar.

The second group of projects include:

- TH 33 Concept B – Split Diamond with Collector Distributor or TH 33 Concept D – Split Diamond with Eastbound Collector Distributor.
- TH 45 Concept A – Widen TH 45 Bridges or TH 45 Concept F – Widen TH 45 Bridges with Modified Ramps and Loops.
- Moorhead Overpass – Widen bridge to accommodate a trail or build a separate trail bridge.

The third group of projects include:

- Improve I-35 horizontal alignment at TH 33 to meet 70-mph curve.
- TH 210 Entrance Ramps – Reconstruct ramps to meet 50-mph vertical curve or lengthen acceleration lanes.

## Challenges

MnDOT noted a few challenges as part of its analysis and planning processes. Although the ISATe can be used to perform a safety analysis and predict crashes, ISATe cannot predict crashes for all intersection geometries. The terminal intersection at the TH 33 interchange, which is a roundabout, could not be included in the safety analysis. However, MnDOT noted that excluding it would not bias the planning-level comparison of the final design concept alternatives, as all alternatives considered a roundabout at that interchange terminal.

More broadly, planning studies of this size and complexity must often contend with rapidly changing conditions and external decisions. Cloquet, MN, which contains part of the study area, is growing and constantly changing. The I-35 study took a comprehensive look at the current and expected conditions at the time, but the community and road conditions often change before a project can advance to the next stage. For example, a reduced conflict intersection project was subsequently funded on TH 33 just outside of the planning limits of the I-35 study. Although the intersection project should improve safety, it was not included or modeled in this study.

Additionally, the project team noted challenges related to public engagement. First, members of the public who gave input into the project may not be the same people who work or live in the area. Second, it can be difficult for members of the public who are not familiar with safety

research to understand modeled crashes, as they may not be intuitive for everyone. This may cause people to not accept aspects of the project or analysis and reinforces the need to convey safety benefits in relatable terms depending on the audience.

## Conclusions

The I-35 planning study is an example of incorporating quantitative safety analysis as part of a comprehensive review process that includes other dimensions of the transportation system (i.e., mobility, accessibility, and environmental stewardship). MnDOT's work to obtain stakeholder feedback and analyze existing safety conditions allowed the project team to establish safety as a project need. Further evaluation of specific needs led MnDOT to develop a suite of alternatives that balanced environmental sensitivity with access and safety. ISATe provided the technical capacity to assess the study area's baseline conditions based on existing geometrics and traffic and estimate predicted crashes based on forecast conditions. Furthermore, the benefit-cost analysis provided further confidence that MnDOT's alternatives will be cost effective, as well as provided a high level of benefit to users of the I-35 corridor.

## References


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