DEPARTMENT OF TRANSPORTATION

Speed Limit Change (55 mph to 60 mph) Safety Evaluation

Richard Storm, Principal Investigator
HDR, Inc.

February 2020

Research Project
Final Report 2020-06

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Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
MN 2020-06		

4. Title and Subtitle	5. Report Date
Speed Limit Change (55 mph to 60 mph) Safety Evaluation	February 2020
	6.

7. Author(s)	8. Performing Organization Report No.
Taha Saleem; Raghavan Srinivasan; Daniel Levitt; Mike Vann; Amy Worzella; and Richard Storm	

9. Performing Organization Name and Address		10. Project/Task/Work Unit No.
Highway Safety Research Center University of North Carolina 730 Martin Luther King Jr. Blvd, CB # 3430 Chapel Hill, NC 27599-3430	Lakeside Engineers 909 North Mayfair Rd Wauwatosa, WI 53226	11. Contract (C) or Grant (G) No.

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Minnesota Department of Transportation Office of Traffic Engineering 1500 W. County Rd B2, MS 725 Roseville, Minnesota 55113	Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

http://mndot.gov/research/reports/2020/202006.pdf

16. Abstract (Limit: 250 words)

The objective of this study was to evaluate the safety impacts of increasing the speed limit from 55 mph to 60 mph on two-lane, two-way state highway road segments in Minnesota. An empirical Bayes (EB) before-after analysis was used to estimate crash modification factors (CMFs) for both segments and intersections. The segment analysis showed a 7 percent increase in total crashes that was statistically significant, alongside insignificant increases/decreases in injury and run-off-road and head-on crashes. The range of most of the segment CMFs hovered close to 1 (essentially meaning that the crashes either remained unchanged or the change was minor). The intersection analysis was split into two groups (all traffic control types and thru-stop control only). The aggregate CMFs for all intersections within these two groups showed that most of the CMFs hovered close to 1. Analysis was also performed on four subgroups (3- and 4-leg, lighting/no lighting) within the two main intersection groups. Disaggregating the intersections into further groups led to smaller sample sizes that led to higher standard errors, showing a widespread range of CMFs around 1 for the individual crash types and severities. The aggregate analysis conducted using all the segment and intersection data showed a minor increase/decrease in the total and injury crashes. This aggregate result along with before-and-after operating speed data from another Minnesota Department of Transportation (2019) study showing that the 85th percentile operating speed remained the same and that mean operating speeds increased by 1 mph following the speed limit increase can lead to a conclusion that the speed limit increase from 55 mph to 60 mph had a very minor to no effect on total and injury crashes or operating speeds.

17. Document Analysis/Descriptors	18. Availability Statement
Traffic speed, Speed limits, Bayes' theorem, Crash modification factors	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	53	

SPEED LIMIT CHANGE (55 MPH TO 60 MPH) SAFETY EVALUATION

FINAL REPORT

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February 2020

Published by:

Minnesota Department of Transportation
Office of Traffic Engineering
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ACKNOWLEDGEMENTS

This research was funded by the Minnesota Department of Transportation (MnDOT) as part of contract entitled *Traffic Safety Evaluation*, which was led by HDR. The authors acknowledge the support of MnDOT in providing the data that was used in this research. The authors also thank MnDOT for their support and guidance throughout this effort.

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EXECUTIVE SUMMARY

The objective of this study is to evaluate safety impacts of increasing the speed limit from 55 mph to 60 mph on two-lane, two-way state highway road segments in Minnesota. An empirical Bayes (EB) before-and-after analysis is used to estimate crash modification factors (CMFs) for both road segments and intersections. The EB methodology is considered rigorous in that it accounts for possible bias due to regression to the mean (RTM) and uses safety performance functions (SPFs) to account for changes in exposure and time trends, and it has been found to reduce the level of uncertainty in the estimates of the safety effect. The CMFs (using EB analysis) are estimated using the expected number of crashes without the treatment along with the number of reported crashes after the treatment. Crash data from 2012 through 2018 is used in the analysis, with the treatment group consisting of sites where speed limits were changed in or after 2015. This led to the before period varying between 3 and 5 years and the after period varying between 1 and 3 years.

The segment analysis showed a 7 percent increase in total crashes that was statistically significant, alongside insignificant increases/decreases in injury and run-off-road and head-on crashes. The range of most of the segment CMFs hovered close to 1 (essentially meaning that the crashes either remained unchanged or the change was minor). The intersection analysis was split into two groups (all traffic control types and thru-stop control only). The aggregate CMFs for all intersections within these two groups showed that most of the CMFs hovered close to 1. Analysis was also performed on four subgroups (3- and 4-leg, lighting/no lighting) within the two main intersection groups. Disaggregating the intersections into further groups led to smaller sample sizes that led to higher standard errors, showing a widespread range of CMFs around 1 for the individual crash types and severities.

The aggregate analysis conducted using all the segment and intersection data showed a very minor increase/decrease in the total and injury crashes with total crashes showing an average increase of 2.9%, KABC (K – killed, A – incapacitating injury, B – non-incapacitating injury, and C – possible injury) injury crashes showing an average increase of 2.5%, while KAB injury crashes showed an average decrease of 0.5%. This aggregate result along with before-and-after operating speed data from another MnDOT (2019) study showing that the 85th percentile operating speed remained the same and that mean operating speeds increased by 1 mph following the speed limit increase, which can lead to a conclusion that the speed limit increase from 55 mph to 60 mph had a very minor to no effect on total and injury crashes or operating speeds. The nominal impact to operating speeds and crashes indicates the effectiveness of MnDOT's data driven process to determine which corridors are suitable for a 60-mph speed limit.

CHAPTER 1: INTRODUCTION

The Minnesota legislature passed legislation in 2014 mandating the Minnesota Department of Transportation (MnDOT) evaluate a speed limit increase from 55 mph to 60 mph on the two-lane state highway system (see 2014 Laws of Minnesota, Chapter 312, Article 11, Section 36)[1]. Minnesota has approximately 7,000 miles of two-lane, two-way roadways that are affected by this legislation[2]. The legislation[1] required engineering and traffic investigations to determine segments where speed limits could be reasonably and safely increased to 60 mph. As a result of these investigations, the speed limit was increased to 60 mph on 5,240 miles of the two-lane state highway system. MnDOT had previously increased speeds to 60 mph on 1,550 mile of two-lane highways[2]. When all of the speed limit signs are installed, 81 percent of the two-lane, two-way state highways will have a posted speed limit of 60 mph[1].

The objective of this *Speed Limit Change (55 mph to 60 mph) Safety Evaluation* task is to review and evaluate the safety impacts for two-lane, two-way state highway road segments. Thus, this study evaluates state highway segments where speed limits were changed from 55 mph to 60 mph using a before-and-after evaluation.

Typically, the safety effect of engineering treatments are expressed in the form of crash modification factors (CMFs). The CMF is a multiplicative factor that can be used to estimate the expected number of crashes after implementing a given treatment. With a CMF, the percentage change in crashes due to the treatment is estimated as 100(1-CMF). Hence, a CMF of 1.0 indicates that the engineering treatment did not have any effect on crashes. A CMF of 0.8 indicates that the engineering treatment is expected to reduce crashes by 20%; similarly, a CMF of 1.2 indicates that the engineering change is expected to increase crashes by 20%. In this study, CMFs are estimated for the following locations, crash types, and crash severities:

- Locations:
  - Two-lane, two-way state highway road segments (excluding intersections), and
  - Intersections on two-lane, two-way state highway road segments:
    - 3-Legged intersections with lighting
    - 3-legged intersections with no lighting
    - 4-legged intersections with lighting
    - 4-legged intersections with no lighting

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[1] 2014 Laws of Minnesota, Chapter 312, Article 11, Section 36. https://www.revisor.mn.gov/laws/2014/0/312/

[2] *Evaluation of Certain Trunk Highway Speed Limits. Minnesota Department of Transportation*. 2019. https://www.dot.state.mn.us/govrel/reports/2019/2018%20TH%20Speed%20Limit%20Report-final%20year%20report.pdf

- Crash Types:
    - All types combined (total)
    - Angle crashes
    - Head-on crashes
    - Rear-end crashes
    - Run-off-road crashes
    - Sideswipe same direction crashes
- Crash Severities:
    - Total crashes (also referred to as KABCO crashes)
    - Fatal and all injury crashes (also referred to as KABC crashes)
    - Fatal and serious/suspected injury crashes (also referred to as KAB crashes)

Evaluation of pedestrian and bicyclist crashes was also considered; however, there were not enough crashes to conduct a reliable statistical evaluation.

CHAPTER 2: OVERVIEW OF EVALUATION APPROACH

This evaluation follows a three-step approach:

1. Reviewing existing literature on the safety effectiveness of speed limit and operating speed changes.
2. Identifying data required for this evaluation and then gathering and compiling the data in a relational database.
3. Performing a statistical analysis on the roadway, traffic volume, and crash data, including activities to build an analytical file suitable for the statistical analysis.

2.1 SAFETY EVALUATION METHODS

The various safety evaluation methods fall under two broad categories: before-after and cross-sectional studies. Before-after studies include all techniques by which one may study the safety effect of some treatment that has been implemented on a group of sites. On the other hand, cross-sectional studies include those where one is comparing the safety of one group of sites having some common feature (treatment of interest) to the safety of a different group of sites not having that feature in order to assess the safety effect of the treatment (Carter *et al.*, 2012).

There is a general consensus in the safety community that well-designed before-after studies provide more reliable estimates of safety effects compared to cross-sectional studies. This is because before-after studies are less prone to confounding (aka other influences) since the study evaluates the same roadway unit used by probably the same users in the before and after period (Elvik, 2011). Confounding, on the other hand, is a big issue in cross-sectional studies and can confuse the association between an exposure and an outcome.

Safety effects derived from before-after studies are based on the change in safety due to the implementation of a treatment. The most practically established approach for before-after evaluations is the empirical Bayesian method (EB). The EB approach associate a reference group (treatment not applied) which is similar to treated sites (treated group) and is introduced to offer referential information for before-after evaluations, as illustrated in Figure 1 (Chen, 2013).

The five groups as identified in Figure 1 form a grid with the dimension of reference and treated groups crossed by dimension of before and after periods. The goal here is to seek a CMF (or crash reduction rate) through a safety comparison between groups 4 and 5. The EB approach estimates the expected safety improvement of the treatment that is being evaluated (Chen, 2013).

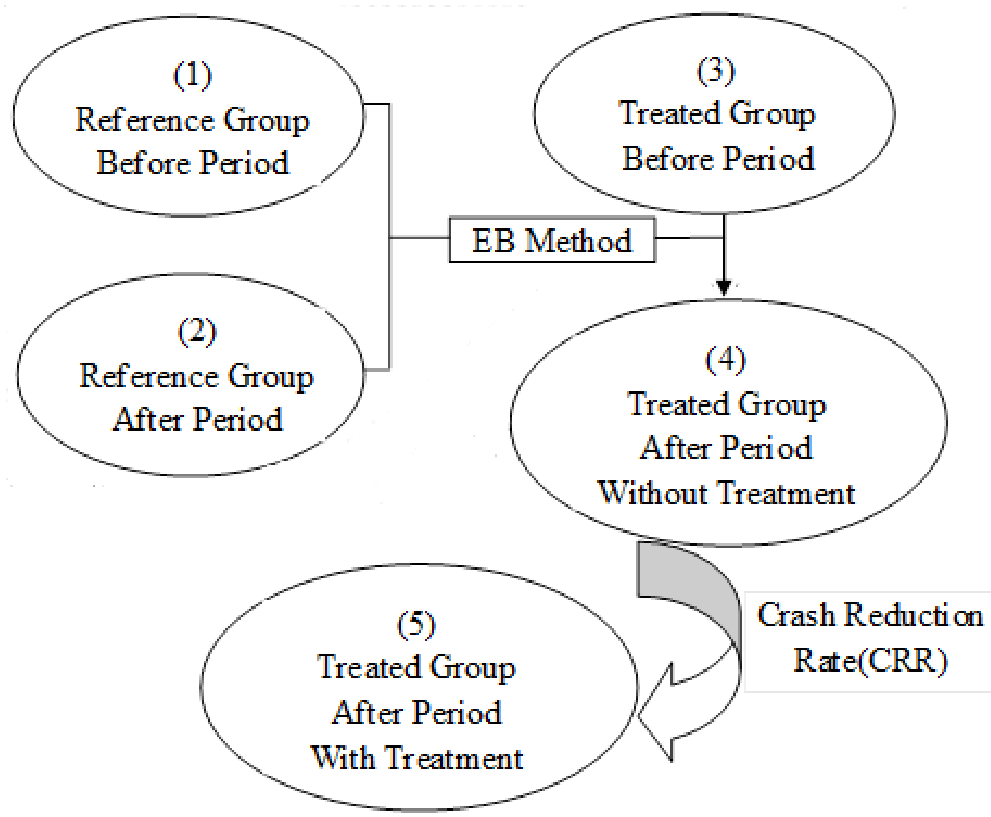

Figure 1. Logical Framework for Before-After Evaluations.

The objective of the EB before-after study is to estimate the number of crashes that would have occurred at an individual treated site in the after period had the treatment not been implemented. The advantage of the EB approach is that it correctly accounts for changes in crash frequencies before and after a treatment that may be due to regression to the mean (RTM). Often, agencies select high crash locations for implementing treatments, and if the possible bias due to RTM is not properly accounted for, the evaluation may overestimate the safety effect of the treatment. In accounting for RTM, the number of crashes expected in the before period without the treatment is estimated as a weighted average of the number of crashes observed in the before period at treated sites and the number of crashes predicted at treated sites based on untreated reference sites with similar characteristics. The 1st edition of the Highway Safety Manual (AASTHO, 2010) considers the EB approach as an effective approach for conducting reliable before-after studies.

CHAPTER 3: LITERATURE REVIEW

Speed limits are usually set to inform drivers of the highest speed that is appropriate for ideal traffic, road, and weather conditions. A literature review scan shows that many studies were conducted to evaluate the safety impacts of changing speed limits. The results of these studies generally show that increasing speed limits can negatively affect safety. For example, a 2019 IIHS study shows that speed limit increases in the past 25 years are tied to over 3700 deaths in the US (IIHS, 2019). The study found that a 5 mph increase in the maximum speed limit was associated with 8% and 3% increases in fatality rates on interstates/freeways and other roads, respectively.

Sayed and Sacchi (2016) evaluated the safety impacts of increasing speed limits on rural highways in British Columbia (Canada) following a speed limit review initiated by the Ministry of Transportation and Infrastructure (MoTI) of British Columbia in 2013. MoTI conducted over 300 speed surveys to measure 85^{th} percentile operating speeds on approximately 9100 km of rural provincial highway segments. The surveys found that the 85^{th} percentile speed on the surveyed segments was 10 km/h higher than the corresponding posted speed limits. As a result of the review, MoTI recommended increasing speed limits on approximately 1300 km of rural provincial highway segments (65 sections). Majority of the sections had a 10 km/h speed limit increase (216 km of segments went from 80 km/h to 90 km/h, 548 km of segments went from 90 km/h to 100 km/h, 146 km of segments went from 100 km/h to 110 km/h, and 377 km of segments went from 110 km/h to 120 km/h), while a small section of 19.2 km had a 20 km/h speed limit increase going from 80 km/h to 100 km/h. Sayed and Sacchi conducted a full Bayesian before-after evaluation using the approximately 1300 km (65 sections) of rural provincial highway segments recommended for increased speed limits by MoTI as their treatment group along with approximately 1850 km (95 sections) of rural provincial highway segments that did not undergo a speed limit increase as their comparison group. They found speed limit increases associated with a statistically significant 11.1% increase in fatal and injury crashes.

De Pauw *et al.* (2014) investigated the safety effects of reducing speed limits from 90 km/h to 70 km/h on roads in the Flemish Region of Belgium. Flemish government, during 2001 and 2002, implemented lower speed limits of a large number of highways in a bid to favorably influence traffic safety. They used four main criteria (one of which had to be met) to select candidate locations: road sections without cycle paths or with cycle lanes close to roadways; road sections with obstacles close to roadway with a high risk of collision; road sections outside urban areas but with high building density and a high number of vulnerable road users; and road sections on which severe crashes occurred in the past. Reduced speed limits were often only restricted at specific sections of roads (e.g. sections between two intersections or sections between two parts of an urban environment) and no enforcement and educational efforts were combined with this change (only traffic signs were updated). De Pauw *et al.* evaluated safety at 61 of the treated road sections with a total length of 116 km. They excluded road sections where other measures (in addition to the speed limit reduction) were performed that could impact speed and safety. Of the 61 road sections in their treated group, 72% were located in rural areas and 80% were categorized as local roads. The comparison group consisted of 19 road sections with a total length of 53 km. They conducted a before-after with comparison group analysis to determine the effectiveness of lowering speed limit at each of the 61 treated sections. They found a decrease in injury crashes at 62% of the treated sections. Disaggregate analysis showed a decrease in injury crashes at intersections for 43% of the treated sections and at segments for 70% of the treated sections. To account for the overall safety effect, they carried out a meta-analysis using the effectiveness at each individual section. The meta-analysis showed a non-significant 5% and 6% reduction in injury and severe injury crashes, respectively.

Jaarsma *et al.* (2011) investigated the safety effects of reducing speed limits from 80 km/h to 60 km/h on rural roads in the Netherlands. Their treatment group consisted of 851 km of minor roads in 20 different rural areas where the speed limit was reduced from 80 km/h to 60 km/h. Minor rural roads in this paper are defined as roads with one lane for two-way traffic along with paved shoulders and a pavement width between 2.5 and 5.5 m. The specific criteria used to select the segments for the treatment group is not mentioned in the paper. The comparison group consisted of 2105 km of comparable roads with 80 km/h speed limit. The results of the before-after with comparison group analysis shows statistically significant 24% and 27% overall reduction in fatal and fatal plus injury crashes, respectively. Disaggregate analysis shows statistically significant reduction of 44% and 55% in fatal and fatal plus injury crashes, respectively at intersections.

Parker (1997) in his study examined the safety effects of raising and lowering speed limits for urban and rural non-limited access highways in 22 States. Experimental sites in this study were selected based on various considerations: sections less than 0.5 mi in length were generally not selected; sections that were recently reconstructed or were subject to construction (apart from regular maintenance) before or after the speed limit changes were not selected; sections with more than one speed limit change during the study period; and sections were selected to represent wide range of urban and rural geographic conditions. The site selection criteria led to selecting three different groups for which safety effects of speed limit changes were evaluated. The first group consisted of 58 experimental sites where speed limits were lowered with a 5 mph speed limit reduction at 14 sites, a 10 mph speed limit reduction at 34 sites, and a 15 or 20 mph speed limit reduction at 10 sites. Using simple before-after analysis, the study finds a 17.29% increase in total crashes for lowering the speed limit by 5 mph, a 3.91% reduction in total crashes for a lowering the speed limit by 10 mph, and a 5.62% reduction in total crashes for lowering the speed limit by 15 or 20 mph. Aggregate analysis over all 58 sites shows a 0.8% and 1.5% increase in total and fatal plus injury crashes, respectively. The second group consisted of 41 experimental sites where speed limits were raised with a 5 mph speed limit increase at 26 sites and a 10 or 15 mph limit increase at 15 sites. Using simple before-after analysis, the study finds a 8.28% reduction in total crashes for a raising the speed limit by 5 mph, and a 15.21% reduction in total crashes for raising the speed limit by 10 or 15 mph. Aggregate analysis over all 41 sites shows a 9.98% and 3.21% reduction in total and fatal plus injury crashes, respectively. The third group consisted of 55 experimental sites, of which, 21 sites had speed limits within 5 mph of the 85^{th} percentile speed (speed limits were raised to within 5 mph of the 85^{th} percentile speed at these sites) and 34 sites had speed limits more than 5 mph below the 85^{th} percentile speed (speed limits were lowered more than 5 mph below the 85^{th} percentile speed at these sites). Using simple before analysis, the study finds an 8.32% reduction in total crashes at sites where the speed limits were raised to within 5 mph of the 85^{th} percentile speed, and a 0.25% increase in total crashes for sites where the speed limits were lowered more than 5 mph below the 85^{th} percentile speed.

Furthermore, this study also explored changes in driver behavior with changes in speed limits. The review of the before and after speed data at each site revealed that differences in mean speeds, standard deviations of speeds, 85th percentile speeds, and other percentile speeds were generally less than 2 mi/h and were not related to the amount the posted speed limit was changed.

Acqua and Russo (2011) analyzed 984 km of low volume roadways (AADT < 1000) in Southern Italy. Of the 984 km of the low volume roadways analyzed 232 km are situated on flat/rolling terrains (vertical grade < 6%) and 752 km are situated on mountainous terrains (vertical grade > 6%). The main goal of this study is to calibrate SPFs to predict injury crashes per km per year as a function of volume, mean operating speed, curvature, vertical grade, and roadway width on low volume roadways. Curvature is this study is defined at three levels; low for curve radius between 400 and 500 m, medium for curve radius between 150 and 400m, and high for curve radius less than 150 m. SPFs were calibrated separately for low volume roadways on flat/rolling terrains and low volume roadways on mountainous terrains. Their findings suggest that for a specific combination of roadway width and curvature, the number of injury crashes per km per year increase with speed. Alternatively they find that there can be a reduction in injury crashes per km per year with no change in speeds but only in specific combinations of roadway width and curvature. One of the examples of various combinations provided in the study where these findings were validated included low curvature roads on flat/rolling terrain with roadway widths of 6 and 9 m. Both of these combinations of roads would see an increase in injury crashes with an increase in speed, however, if the speeds are kept consistent, a decrease in injury crashes can be seen going from a low curvature road with width of 9 m to a low curvature road with a width of 6 m.

Ksaibati *et al.* (2009) in their study developed a rural road safety program for counties in Wyoming. One of the purposes of this program was to help counties identify high-risk low volume rural road locations by developing a methodology for crash prediction at such locations. To develop the crash prediction model they used data from 36 low volume rural roads. Traffic volume and 85th percentile speed were used as predictor variables. Traffic volumes on the roads analyzed ranged from 35 vehicles/day to 1468 vehicles/day and the 85th percentile speeds on these roads ranged from 30 mph to 70 mph. They found that higher volumes combined with higher speeds will result in more crashes.

Vadeby and Forsman (2018) analyzed the effects of both increased and reduced speed limits as well as changes in actual driving speeds due to the changed speed limits following a review of speed limits on the national rural road network by the Swedish Transport Administration in 2008. The review the Swedish Transport Administration resulted in changed speed limits on approximately 20500 km of rural roads (consisting of two-lane rural roads, three-lane rural roads with alternating passing lanes, and motorways) , of which, 2700 km of roads saw an increase in speed limits and 17800 km of roads saw a reduction in speed limits. A reduction in speed limits from 90 km/h to 80 km/h on rural roads resulted in the number of fatalities to decrease by 14 per year, while no significant changes were seen for number of seriously injured. An increase in speed limit from 100 km/h to 120 km/h on motorways was associated with an increase of 15 per year in the number of seriously injured, but no significant changes were seen for the number of deaths. Speed measurement surveys show that a decrease in speed limit with 10 km/h led to a decrease of mean speeds of around 2–3 km/h and an increase of the speed limit with 10 km/h resulted in an increase of mean speed by 3 km/h.

Gayah *et al.* (2018) in their study evaluated the operational and safety impacts of setting posted limits below engineering recommendations using data from rural two- and four-lane roads in Montana. They conducted an empirical Bayes before-after analysis using data from 14 sites (41 miles) where the posted speed limit was reduced from an engineering recommended value to a lower value (comparison group consisted of 38 sites or 131 miles of roadway). The CMFs suggest that setting speed limits 5 mph below the engineering recommended value is associated with a statistically significant reduction in total crashes by 56%, fatal and injury crashes by 40%, and PDO crashes by 57%. Setting speed limits 10 mph below the engineering recommended value is associated with a statistically significant reduction in total crashes by 16% and PDO crashes by 34%, while fatal and injury crashes saw a statistically significant increase of 45%. Setting speed limits 15 mph or more below the engineering recommended value is associated with non-statistically significant increases in total crashes by 21%, fatal and injury crashes by 72%, and PDO crashes by 12%. The operating speed evaluation conducted as a part of this study suggests that drivers tend to comply more closely with the speed limit when the posted speed limit set equal to or just 5 mph below the engineering recommended value. Setting speed limits more than 5 mph below the engineering recommended value saw an increase in both mean and 85th percentile speeds. They also found that intermittent speed enforcement only has nominal effects of operating speeds, while heavy speed enforcements within low speed limit zones reduces both mean and 85th percentile speeds by about 4 mph increasing the likelihood of speed limit compliance.

Gitelman *et al.* (2017) in their study explored the relationship between travel speeds and accidents, while accounting for traffic exposure and road infrastructure on 179 sections of single-carriage (i.e. rural two-lane) roadways in Israel. They developed two crash prediction models using speed measurements in day and night hours. The found that both in day and night hours, under any road infrastructure condition, the number of injury accidents increases with an increase in the segment mean speed, while controlling for traffic exposure and road infrastructure conditions. The also evaluated the safety impact of speed variance (the standard deviation of the mean speed) and found that the impact trend was inconsistent where an increase in the speed variance was associated with a reduction in day hour accidents and with an increase in night hour accidents.

Monsere *et al.* (2018) in their study analyzed the speed and crash performance changes for 1400 miles of Oregon highways and interstates where speed limits were increased in 2016 by the Oregon legislature. The legislature raised speed limits to 70 mph for cars and 65 mph for trucks on interstates and 65 mph for cars and 55 mph for trucks on rural two-lane highways. They found that average operating speeds at the highways that had a speed limit increase showed a statistically significant 3 mph increase along with increases in both the average and percentage of vehicles exceeding 65, 75, and 85 mph. Their preliminary crash analysis found that both the total and total truck-involved crashes increased at a rate that was expected based on changes in traffic volume and the changes in the control sections. Fatal and severe injury crashes did not appear to increase more than the control section for interstates, but did increase for rural two-lane roads. However, overall on both interstates and rural two-lane highways, there was a reduction in fatal and severe injury crashes involving trucks.

CHAPTER 4: EVALUATION METHODOLOGY

The EB methodology for before-after studies was used for this evaluation. As mentioned earlier, this methodology is considered rigorous in that it accounts for the possible bias due to the RTM. This procedure uses a reference group of similar but untreated sites, safety performance functions (SPFs) to account for changes in exposure, time trends, and has been found to reduce the level of uncertainty in the estimates of the safety effect.

The following steps are needed to conduct an EB before-after evaluation:

1. Identify a reference group without the treatment, but similar to the treated sites in terms of the major factors that affect crash risk including traffic volume and other site characteristics.
2. Estimate SPFs using data from the reference entities relating crashes to the characteristics of the entity. In some cases, if it is not possible to find a reference group similar to the treatment group, or when the treatment is implemented system-wide, the before data from the treatment entities is used along with reference or comparison entities to estimate the SPFs. In fact, in this evaluation, the before data from the treatment sites were combined with the reference sites for estimating SPFs.
3. In estimating SPFs, calibrate annual calibration factors (ACFs) to account for the temporal effects (e.g., variation in weather, demography, vehicle population, and crash reporting) on safety performance. The ACF for a particular year is the ratio of the observed crashes to the predicted crashes from the SPF.
4. Use the SPFs, ACFs, and site characteristics for each year in the before period for each treatment site to estimate the number of crashes that would be predicted for the before period.
5. Calculate the EB estimate of the expected crashes in the before period at each treatment site as the weighted sum of the actual crashes in the before period and predicted crashes from step 4.
6. For each treatment site, estimate the product of the EB estimate of the expected crashes in the before period and the SPF predictions for the after period divided by the SPF predictions for the before period. This is the EB expected number of crashes in the after period that would have occurred had there been no treatment. The variance of this expected number of crashes is also estimated in this step. The expected number of crashes without the treatment along with the variance of this parameter and the number of reported crashes after the treatment is used to calculate the safety effect of the treatment (θ) along with the standard error, which is an estimate of the precision of the estimate of the safety effect. It is important to note that θ is the same as a CMF.

Based on the safety effect (θ), the percent change in crashes is calculated as $100(1-\theta)$. Therefore a value of $\theta = 0.9$ with a standard of error of 0.05 indicates a 10% reduction in crashes with a standard error of 5%. Conversely, a value of $\theta = 1.2$ with a standard of error of 0.1 indicates a 20% increase in crashes with a standard error of 10%. Further details about the equations involved in estimating θ and its standard error are available in Appendix A.

CHAPTER 5: DATA COMPILATION AND DATABASE DEVELOPMENT

Steps needed for development of the relational database are shown in Figure 2. Data was first inspected for inconsistencies and anomalies (Step 1). Data collected prior to 2016 was geospatially referenced using MnDOT's Transportation Information System (TIS), while data collected from 2016 to 2018 were referenced by MnDOT's new Linear Referencing System (LRS). To be relatable, data from the two systems were spatially joined in a geographic information system (GIS) (Step 2). Finally, associated roadway, crash, traffic volume, and intersection data are related to the segments with speed limit change (i.e., treatment) and segments with no speed limit change (i.e., reference/non-treatment). Details as to the methods, challenges, and assumptions in the database development can be found in Appendix B.

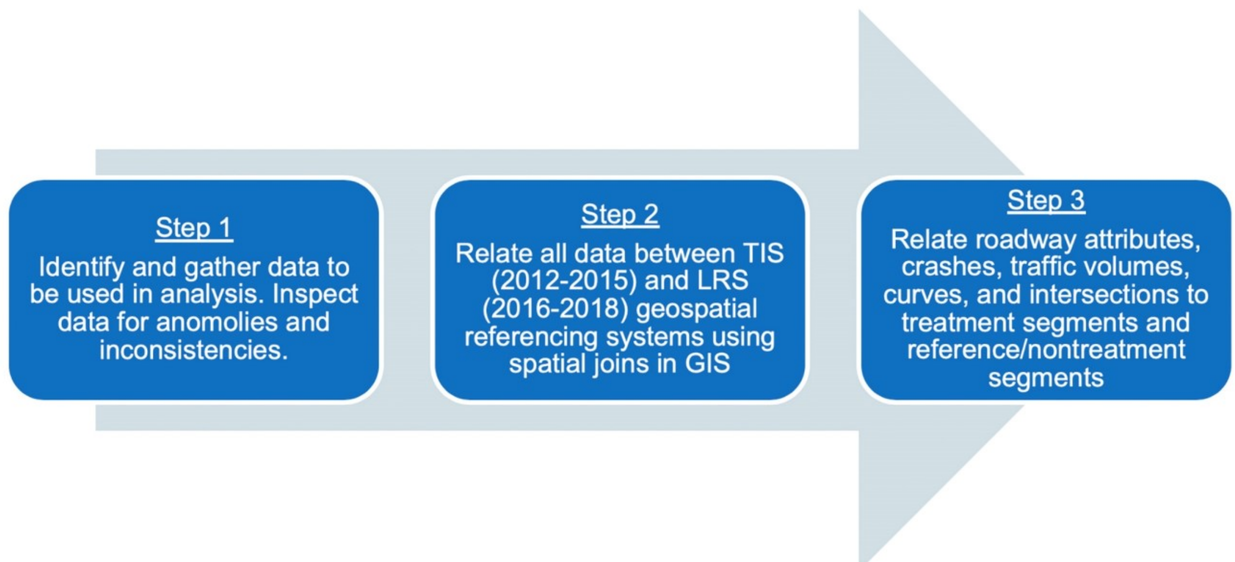

Figure 2. Database Development Approach.

5.1 DESCRIPTIVE STATISTICS

The treatment group consisted of sites where the speed limit was changed in 2015, 2016, and 2017. The reference/non-treatment sites included locations where the speed limit was modified in 2018, locations where the speed limit change will be modified (2019 onwards), and locations where there are no plans for the speed limit to be modified. Because evaluation's available crash data was 2012 through 2018, sites were distributed into three groups:

- Group 1: Sites where speed limit was changed in 2015, 2016, and 2017; at least one year of after crash data available.
- Group 2: Sites where speed limit were changed in 2018 or will be changed in the future; no after crash data available.

- Group 3: Sites where there are no plans for speed limits to be modified.

Table 1 through Table 11 provide summary statistics for segments and intersections in these three groups that were used in the analysis. It should be noted that for estimating safety performance functions (SPF), data from Group 3 alongside before data from Groups 1 and 2 were used. These SPFs were then used to estimate the EB estimates and the resulting crash modification factors (CMFs) using data from Group 1. More discussion on SPF and CMF estimation can be found in Section 6 of this report. With crash data available from 2012 – 2018, the Group 1 before period varied between 3 – 5 years and the after period varied between 1 – 3 years.

Table 1. Segment Summary Statistics

Site Type	Number of Sites	Length (mi)	Average AADT	Average Degree of Curvature	Number of Site-Years	Mile-Years
Group 1	5739	1909.11	2347.75	0.1602	34434	11454.66
Group 2	8413	2602.04	2242.95	0.2288	55960	17307.76
Group 3	5506	1421.99	2633.32	0.3501	38542	9953.93

Table 2. Intersection Summary Statistics

Intersection Type	Number of Sites	Average AADT
3-Leg (Group 1)	1722	3092.93
3-Leg (Group 2)	2563	2871.72
3-Leg (Group 3)	1882	4730.29
4-Leg (Group 1)	1191	2413.01
4-Leg (Group 2)	1470	2359.19
4-Leg (Group 3)	827	4353.81

Table 3. Crash Summary Statistics for Group 1 Segments

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	5	0.092	3169
Injury (KABC)	0	3	0.035	1208
Injury (KAB)	0	2	0.019	657
Run off Road	0	4	0.039	1369
Head On	0	3	0.009	334

Table 4. Crash Summary Statistics for Group 2 Segments

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	6	0.092	5169
Injury (KABC)	0	5	0.033	1850
Injury (KAB)	0	3	0.019	1066
Run off Road	0	4	0.046	2569
Head On	0	3	0.009	490

Table 5. Crash Summary Statistics for Group 3 Segments

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	9	0.111	4260
Injury (KABC)	0	4	0.041	1570
Injury (KAB)	0	3	0.022	841
Run off Road	0	5	0.048	1836
Head On	0	3	0.011	416

Table 6. Crash Summary Statistics for 3-Legged Group 1 Intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	6	0.1048	1262
Injury (KABC)	0	4	0.0415	500
Injury (KAB)	0	4	0.0203	245
Angle	0	4	0.0136	164
Rear End	0	4	0.0252	303
Side Swipe Same Direction	0	2	0.0066	79

Table 7. Crash Summary Statistics for 4-Legged Group 1 Intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	6	0.1638	1363
Injury (KABC)	0	4	0.0672	559
Injury (KAB)	0	3	0.0350	291
Angle	0	5	0.0493	410
Rear End	0	5	0.0344	286
Side Swipe Same Direction	0	2	0.0101	84

Table 8. Crash Summary Statistics for 3-Legged Group 2 intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	14	0.1041	1868
Injury (KABC)	0	4	0.0386	692
Injury (KAB)	0	3	0.0189	339
Angle	0	4	0.0122	219
Rear End	0	3	0.0208	373
Side Swipe Same Direction	0	4	0.0062	111

Table 9. Crash Summary Statistics for 4-Legged Group 2 Intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	13	0.1648	1696
Injury (KABC)	0	6	0.0673	693
Injury (KAB)	0	4	0.0357	367
Angle	0	4	0.0476	490
Rear End	0	11	0.0351	361
Side Swipe Same Direction	0	3	0.0099	102

Table 10. Crash Summary Statistics for 3-Legged Group 3 Intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	19	0.1816	2392
Injury (KABC)	0	5	0.0660	870
Injury (KAB)	0	4	0.0295	389
Angle	0	3	0.0229	302
Rear End	0	12	0.0553	729
Side Swipe Same Direction	0	4	0.0119	157

Table 11. Crash Summary Statistics for 4-Legged Group 3 Intersections

Crash Type	Minimum (/site/year)	Maximum (/site/year)	Average (/Site/Year)	Sum
Total	0	18	0.3939	2280
Injury (KABC)	0	7	0.1472	852
Injury (KAB)	0	4	0.0674	390
Angle	0	6	0.1026	594
Rear End	0	9	0.1302	754
Side Swipe Same Direction	0	6	0.0278	161

CHAPTER 6: RESULTS AND DISCUSSION

As described in Section 4, the evaluation's first step is to estimate a safety performance function (SPF). Generalized linear modeling was used to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. SPFs were estimated for target crash types and crash severities identified in Section 1. These SPFs and the annual calibration factors (ACFs) are documented in Appendices C and D, respectively.

6.1 ESTIMATED SEGMENT CRASH SAFETY EFFECTS

The estimated crash safety effects for segments are shown in Table 12. For each crash type, the EB expected crashes in the after period had the speed limit change not been implemented are shown along with the actual number of crashes observed in the after period, the CMF, the standard error of the CMF, and 95% significant range of the CMFs. It is important to note that the expected crashes in the after period without treatment is provided with a decimal, because it is an estimated quantity, unlike the crashes in the after period that are observed.

Table 12. Estimated Segment Crash Safety Effects

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	1191	1111.69	**1.071***	**0.035**	1.002-1.140
Injury (KABC)	456	435.62	**1.046**	**0.052**	0.944-1.147
Injury (KAB)	279	288.22	**0.968**	**0.059**	0.852-1.087
Run off Road	588	565.96	**1.039**	**0.047**	0.947-1.131
Head On	86	88.84	**0.967**	**0.110**	0.751-1.183

** Statistically Significant at the 95-percent Confidence Level*

The results indicate the increasing the speed limits from 55 mph to 60 mph had minor impacts on segment crashes, especially for the more important injury crashes. The total crashes show an increase of 7.1% (statistically significant at the 95% confidence level), along with a 4.6% increase in KABC injury crashes and a 3.9% increase in run off road crashes, both of which were not statistically significant. Reductions in injury (KAB) crashes and head on crashes were 3.2% and 3.3%, respectively, both of these were not statistically significant. The ranges of these CMFs show a widespread of values showing increases, reduction, and no change in crashes.

6.2 ESTIMATED INTERSECTION CRASH SAFETY EFFECTS

Intersections were divided into two different groups (further divided into four different subgroups each) for estimation of crash safety effects. CMFs were estimated for each of the four subgroups, alongside aggregate CMFs for the two groups.

- Intersections on two-lane, two-way state highway road segments – all control types:
    - 3-Legged intersections with lighting (n = 66),
    - 3-legged intersections with no lighting (n = 1656),
    - 4-legged intersections with lighting (n = 92), and
    - 4-legged intersections with no lighting (n = 1099).
- Intersections on two-lane, two-way state highway road segments – thru-stop only:
    - 3-Legged intersections with lighting (n = 64),
    - 3-legged intersections with no lighting (n = 1653),
    - 4-legged intersections with lighting (n = 85), and
    - 4-legged intersections with no lighting (n = 1085).

6.2.1 Intersections Safety Effects (All Traffic Control Types)

The estimated crash safety effects for the four subgroups of intersection with all traffic control types are shown in Tables 13-16. For each crash type, the EB expected crashes in the after period had the speed limit change not been implemented are shown along with the actual number of crashes observed in the after period, the CMF, the standard error of the CMF, and 95% significant range of the CMFs.

Table 13. Intersection Safety Effects (3-Leg Intersection with No Lighting – All Control Types)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	282	269.58	**1.045**	**0.070**	0.908-1.182
Injury (KABC)	111	102.09	**1.085**	**0.113**	0.864-1.306
Injury (KAB)	63	57.78	**1.088**	**0.147**	0.800-1.376
Angle	43	30.36	**1.407****	**0.240**	0.937-1.877
Rear End	80	69.97	**1.139**	**0.142**	0.861-1.417
Side Swipe Same Direction	15	17.42	**0.851**	**0.235**	0.390-1.312

*** Statistically Significant at the 90-percent Confidence Level*

Table 14. Intersection Safety Effects (3-Leg Intersection with Lighting – All Control Types)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	35	38.08	**0.911**	**0.174**	0.570-1.252
Injury (KABC)	7	12.73	**0.541***	**0.212**	0.125-0.957
Injury (KAB)	4	6.26	**0.625**	**0.319**	0.000-1.250
Angle	10	8.31	**1.152**	**0.419**	0.331-1.973
Rear End	9	9.3	**0.943**	**0.340**	0.277-1.609
Side Swipe Same Direction	0	2.36	**0.000**	**-**	-

** Statistically Significant at the 95-percent Confidence Level*

Table 15. Intersection Safety Effects (4-Leg Intersection with No Lighting – All Control Types)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	214	256.82	**0.832***	**0.063**	0.709-0.955
Injury (KABC)	101	110.47	**0.912**	**0.099**	0.718-1.106
Injury (KAB)	68	62.84	**1.078**	**0.144**	0.796-1.360
Angle	69	82.11	**0.837*****	**0.111**	0.619-1.055
Rear End	54	49.82	**1.079**	**0.161**	0.763-1.395
Side Swipe Same Direction	17	19.86	**0.850**	**0.215**	0.429-1.271

** Statistically Significant at the 95-percent Confidence Level*

**** Statistically Significant at the 85-percent Confidence Level*

Table 16. Intersection Safety Effects (4-Leg Intersection with Lighting – All Control Types)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	81	75.85	**1.062**	**0.139**	0.790-1.334
Injury (KABC)	31	27.50	**1.117**	**0.225**	0.676-1.558
Injury (KAB)	16	16.75	**0.941**	**0.258**	0.435-1.447
Angle	41	38.30	**1.057**	**0.199**	0.667-1.447
Rear End	21	15.29	**1.348**	**0.339**	0.684-2.012
Side Swipe Same Direction	3	3.29	**0.869**	**0.512**	0-1.873

The results indicate the increasing the speed limits from 55 mph to 60 mph had varying impacts on intersection crashes at intersections with all traffic control types. Most of the safety effects were statistically insignificant except for total crashes (on 4-leg intersections with no lighting – 16.8% reduction), injury (KABC) crashes (on 3-leg intersections with lighting – 45.9% reduction), angle crashes (on 3-leg intersections with no lighting – 40.7% increase), and angle crashes (on 4-leg intersections with no lighting – 16.3% reduction) showing statistically significant safety effects at various significance levels.

The primary reason for the 40.7% increase in angle crashes at 3-leg intersections with no lighting is s a spike in the reported angle crashes (at 3-leg intersections with no lighting), especially in 2014 and 2015. During the same time, a decline was seen in the number of reported head-on crashes at 3-leg intersections with no lighting (probably, as a result of crash reporting changes between angle and head-on crashes at intersections). This issue corrects itself when accounting for aggregate 3-leg and 4-leg intersections as can be seen in Table 21 in Section 6.2.3, with the aggregate angle crash CMF coming in at 1.023.

The ranges of the CMFs show a wide spread of values showing increases, reduction, and no change in crashes. However, the insignificant results coupled with the fact that some of crash types and severities have low to very low crash counts makes it difficult to conclude the effects of speed limit change on the various crashes.

6.2.2 Intersection Safety Effects (Thru-Stop Only)

The estimated crash safety effects for the four subgroups of intersection with thru-stop control are shown in Tables 17-20. For each crash type, the EB expected crashes in the after period had the speed limit change not been implemented are shown along with the actual number of crashes observed in the after period, the CMF, the standard error of the CMF, and 95% significant range of the CMFs.

Table 17. Intersection Safety Effects (3-Leg Intersection with No Lighting – Thru-Stop only)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	277	265.92	**1.040**	**0.070**	0.903-1.177
Injury (KABC)	110	101.26	**1.084**	**0.113**	0.863-1.305
Injury (KAB)	63	53.84	**1.166**	**0.161**	0.850-1.482
Angle	40	30.1	**1.320**	**0.231**	0.867-1.773
Rear End	80	67.07	**1.154**	**0.144**	0.872-1.436
Side Swipe Same Direction	14	16.36	**0.846**	**0.239**	0.378-1.314

Table 18. Intersection Safety Effects (3-Leg Intersection with Lighting – Thru-Stop only)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	31	35.67	**0.861**	**0.173**	0.522-1.200
Injury (KABC)	6	12.29	**0.479***	**0.202**	0.083-0.875
Injury (KAB)	4	5.95	**0.654**	**0.335**	-0.003-1.311
Angle	8	7.13	**1.070**	**0.425**	0.237-1.903
Rear End	8	8.28	**0.937**	**0.358**	0.235-1.639
Side Swipe Same Direction	0	2.1	**0.000**	**-**	-

** Statistically Significant at the 95-percent Confidence Level*

Table 19. Intersection Safety Effects (4-Leg Intersection with No Lighting – Thru-Stop only)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	212	248.44	**0.852***	**0.065**	0.725-0.979
Injury (KABC)	100	108.34	**0.921**	**0.100**	0.725-1.117
Injury (KAB)	68	61.91	**1.094**	**0.147**	0.806-1.382
Angle	68	78.73	**0.860**	**0.116**	0.633-1.087
Rear End	53	48.69	**1.083**	**0.164**	0.762-1.404
Side Swipe Same Direction	17	19.01	**0.887**	**0.227**	0.442-1.332

** Statistically Significant at the 95-percent Confidence Level*

Table 20. Intersection Safety Effects (4-Leg Intersection with Lighting – Thru-Stop only)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	63	73.61	**0.850**	**0.126**	0.603-1.097
Injury (KABC)	26	28.17	**0.913**	**0.198**	0.525-1.301
Injury (KAB)	15	18.09	**0.817**	**0.228**	0.370-1.264
Angle	35	38.77	**0.890**	**0.181**	0.535-1.245
Rear End	12	13.62	**0.850**	**0.283**	0.295-1.405
Side Swipe Same Direction	3	4.46	**0.625**	**0.371**	0-1.352

The results indicate the increasing the speed limits from 55 mph to 60 mph had varying impacts on intersection crashes at intersections with thru-stop control only. Most of the safety effects were statistically insignificant except for total crashes (on 4-leg intersections with no lighting – 14.8%

reduction) and injury (KABC) crashes (on 3-leg intersections with lighting – 52.1% reduction) showing statistically significant safety effects at the 95% significance level. The ranges of the CMFs show a widespread of values showing increases, reduction, and no change in crashes. However, the insignificant results coupled with the fact that some of crash types and severities have low to very low crash counts makes it difficult to conclude the effects of speed limit change on the various crashes.

6.2.3 Aggregate Intersection Safety Effects

The aggregate estimated crash safety effects for the two main groups of intersections (all traffic control types and thru-stop control only) are shown in Tables 21-22. For each crash type, the EB expected crashes in the after period had the speed limit change not been implemented are shown along with the actual number of crashes observed in the after period, the CMF, the standard error of the CMF, and 95% significant range of the CMFs.

Table 21. Intersection Safety Effects (All Control Types – 3-leg and 4-leg Combined)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	612	640.33	**0.955**	**0.044**	0.870-1.041
Injury (KABC)	250	252.79	**0.988**	**0.069**	0.854-1.123
Injury (KAB)	151	143.63	**1.050**	**0.093**	0.867-1.233
Angle	163	159.09	**1.023**	**0.092**	0.843-1.203
Rear End	164	144.39	**1.134**	**0.099**	0.940-1.328
Side Swipe Same Direction	35	42.95	**0.812**	**0.145**	0.527-1.096

Table 22. Intersection Safety Effects (Thru-Stop only – 3-leg and 4-leg Combined)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	583	623.65	**0.934*** **	**0.044**	0.848-1.020
Injury (KABC)	242	250.06	**0.967**	**0.068**	0.833-1.101
Injury (KAB)	150	139.80	**1.071**	**0.097**	0.882-1.261
Angle	151	154.74	**0.974**	**0.091**	0.795-1.152
Rear End	153	139.68	**1.093**	**0.099**	0.898-1.288
Side Swipe Same Direction	34	41.94	**0.807**	**0.147**	0.519-1.096

**** Statistically Significant at the 85-percent Confidence Level*

The results indicate increasing the speed limits from 55 mph to 60 mph had varying impacts on aggregate intersection crashes at intersections with all traffic control types and thru-stop control only.

For intersections with all traffic control types, a 4.5% reduction was seen in total crashes, alongside a 1.2% reduction in injury (KABC) crashes and a 18.8% reduction is side-swipe same direction crashes, all statistically insignificant. On the other hand, injury (KAB) crashes saw a 5% increase, while angle crashes and rear end crashes saw 2.3% and 13.4% increases, respectively, all of which were statistically insignificant. For intersections with thru-stop control only, a 6.6% reduction was seen in total crashes (statistically significant at the 95% level), alongside a 3.3% reduction in injury (KABC) crashes, 2.6% reduction in angle crashes, and a 19.3% reduction is side-swipe same direction crashes, all pf which were statistically insignificant. On the other hand, injury (KAB) crashes saw a 7.1% increase, while rear end crashes saw a 9.3% increase, both of which were statistically insignificant. The ranges of these aggregate CMFs hover around 1 showing minor increases, minor reductions, and no changes in crashes.

6.3 ESTIMATED AGGREGATE SEGMENT AND INTERSECTION CRASH EFFECTS

The aggregate estimated crash safety effects (for total and injury crashes) for combined segments and intersection sites are shown in Table 23. For each crash type, the EB expected crashes in the after period had the speed limit change not been implemented are shown along with the actual number of crashes observed in the after period, the CMF, the standard error of the CMF, and 95% significant range of the CMFs.

Table 23. Aggregate Safety Effect (All Segments and Intersections Combined)

Crash Type	Crashes in the After Period	Expected Crashes in the After Period without Treatment	CMF	Standard Error of CMF	Range of CMFs (95% Significance)
Total	1803	1752.02	**1.029**	**0.027**	0.975-1.083
Injury (KABC)	706	688.41	**1.025**	**0.042**	0.944-1.107
Injury (KAB)	430	431.84	**0.995**	**0.050**	0.897-1.094

The results indicate the increasing the speed limits from 55 mph to 60 mph has very minor impact when all the segments and intersections are used to derive an aggregate safety effect. Total crashes show a 2.9% increase, alongside a 2.5% increase in the injury (KABC) crashes and a 0.05% reduction in the injury (KAB) crashes. These aggregate results show that increasing the speed limit had very low impact on the total, injury (KABC) and injury (KAB crashes). However, it is important to understand these results align with a study by the Minnesota Department of Transportation (2019), that compared the before and after operating speed changes following the speed limit increase. They found that the 85th percentile operating speed remained at 65 mph both before and after the speed limit change, whereas, the mean operating speed increased by 1 mph from 59 mph in before period to 60 mph in the after period. The operating speed results (summarized in Table 24) are an indication that MnDOT’s data driven process selected corridors appropriate for a 60 mph speed limit.

Table 24. Before-and-After Operating Speed Data

Speed	Before Speed Limit Change	After Speed Limit Change
85th Percentile Speed	65 mph	65 mph
Mean Speed	59 mph	60 mph
Standard Deviation	6.4 mph	6.1 mph
Average of Five Highest Speeds	76 mph	76 mph

Source: Evaluation of Certain Trunk Highway Speed Limits. Minnesota Department of Transportation. 2019

Based on the before and after operating speed data and the aggregate segment and intersection crash safety effects, it can be said that the speed limit increase from 55 mph to 60 mph had a very minor to no effect on total and injury crashes.

CHAPTER 7: CONCLUSIONS

The objective of this study was to evaluate safety impacts of increasing the speed limit from 55 mph to 60 mph on two-lane, two-way state highway road segments. EB analysis was done to estimate CMFs for both segments and intersections.

When interpreting the results, the following should be given consideration:

- In 2016, Minnesota adopted a new crash reporting system that changed how some of the crashes were defined.
- For intersections, only the major road AADT was available and used for SPF development.

The segment analysis showed a 7 percent increase in total crashes that was statistically significant, alongside insignificant increases/decreases in injury, run-off-road, and head-on crashes. The range of most of the segment CMFs hovered close to 1. The intersection analysis was split into two groups (all traffic control types and thru-stop control only). The aggregate CMFs for all intersections within these two groups showed that most of the CMFs hovered close to 1. Analysis was also performed on four subgroups (3- and 4-leg, lighting/no lighting) within the two main intersection groups. Disaggregating the intersections into further groups led to smaller sample sizes that led to higher standard errors, showing a widespread range of CMFs around 1 for the individual crash types and severities.

The aggregate analysis conducted using all segment and intersection data showed a very minor increase/decrease in the total and injury crashes. This aggregate result along with before-and-after operating speed data from another MnDOT (2019) study showing that the 85th percentile operating speed remained the same and that the mean operating speeds increased by 1 mph following the speed limit increase, which can lead to a conclusion that the speed limit increase from 55 mph to 60 mph had a very minor to no effect on total and injury crashes. The nominal impact on operating speeds and crashes shows the effectiveness of MnDOT's data-driven process to determine which corridors are suitable for a 60 mph speed limit.

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APPENDIX A:
EMPIRICAL BAYES (EB) METHODOLOGY

In the EB approach, the estimated change in safety for a given crash type at a site is given by the equation in Figure A-1.

$$\Delta Safety = \lambda - \pi$$

Figure A-1. Equation. Estimated Change in Safety

Where:

λ = Expected number of crashes that would have occurred in the after without the treatment.

π = Number of reported crashes in the after period.

In estimating λ, the effects of regression to the mean and changes in exposure were explicitly accounted for using SPFs. In this effort, the SPFs were estimated using crash data and characteristics of the sites in the reference group (Group 3) and the before-period of the treatment group (Groups 1 and 2). The SPFs were estimated using negative binomial regression. The SPFs were also used to estimate ACFs for each year. The ACFs are defined as the ratio of the total observed crash frequency to the total predicted crash frequency from the SPF, and are calculated for each year. The ACFs are estimated to account for time trends.

The sum of the annual SPF estimates for the before period (P) was then combined with the count of crashes (x) in the before period at a treatment site to obtain an estimate of the expected number of crashes (m) before the treatment was applied.

$$m = w(P) + (1 - w)(x)$$

Figure A-2. Equation. Empirical Bayes Estimates of Expected Crashes in the Before Period

Where the EB weight, w, was estimated from the mean and variance of the SPF estimate using the equation in Figure A-3.

$$w = \frac{1}{1+kP}$$

Figure A-3. Equation. Empirical Bayes Weight

Where:

k = Overdispersion parameter of the negative binomial distribution.

The expected number of crashes in the after period, λ, was calculated by applying a factor to m as seen in the equation in Figure A-4Figure . This factor was the sum of the annual SPF estimates for the after period (A) divided by P.

$$\lambda = m \times \left(\frac{A}{P}\right)$$

Figure A-4. Equation. Empirical Bayes Estimates of Expected Crashes in the After Period

The estimate of λ and variance of λ, were then summed over all sites to obtain λ_{sum} and $Var(\lambda_{sum})$. λ_{sum} was then compared with the sum of count of crashes observed during the after period over all sites (π_{sum}) to obtain the CMF (θ). The safety effect θ was calculated using the equation in Figure A-5 and the standard error of θ was calculated using the equation in Figure A-6.

$$\theta = \frac{{\pi_{sum}}/{\lambda_{sum}}}{1 + \left(\frac{Var(\lambda_{sum})}{{\lambda_{sum}}^2}\right)}$$

Figure A-5. Equation. CMF

$$Standard\ Error\ of\ \theta = \sqrt{\frac{\theta^2\left(\frac{Var(\pi_{sum})}{{\pi_{sum}}^2} + \frac{Var(\lambda_{sum})}{{\lambda_{sum}}^2}\right)}{\left(1 + \frac{Var(\lambda_{sum})}{{\lambda_{sum}}^2}\right)^2}}$$

Figure A-6. Equation. Standard Error of CMF

The percent change in crashes is calculated as $100(1-\theta)$. Therefore a value of $\theta = 0.9$ with a standard of error of 0.05 indicates a 10% reduction in crashes with a standard error of 5%. Conversely, a value of $\theta = 1.2$ with a standard of error of 0.1 indicates a 20% increase in crashes with a standard error of 10%.

APPENDIX B:
DATABASE DEVELOPMENT

B.1 DATA SOURCES

Roadway attribute data, crash data, project data, and traffic volume data required for this evaluation are identified and gathered in accordance with the project Master Data Collection Plan. The data used is statewide for the years 2012 to 2018. The data sources used in this evaluation are as follows:

- Roadway attribute data (e.g., lane widths, shoulder widths)
- Traffic volume data (e.g., average number of vehicles per day, year of data collection)
- Speed Study data (e.g., speed limits, speed limit change date)
- Intersection data (e.g., number of approaches, traffic control type)
- Curve data (e.g., curve radius, curve length)
- Crash data (e.g., crash severity, crash type, crash date)

B.2 ROADWAY FILES

Roadway information from 2009 to 2015 is available from the TIS system, whereas, the roadway information from 2016 to 2018 is available from the LRS system. Travel lane widths were compared between years 2012 and 2018, and any segments that did not match between these years were eliminated from the data set. The following steps identify how data was extracted from the LRS and TIS systems and how it was converted from the TIS system to the LRS system.

1) Primary Roadway File (2016-2018)

   Roadway information from the LRS system (2016-2018) was located in two files:

   a) An ArcGIS line file that contains basic roadway information in segments, and
   b) A table that contains additional information for the roadway segments (59 columns of data).

   The roadway information is for the entire state, which results in a very large data table (59 columns, over 300,000+ rows), and thus it became necessary to divide it into several smaller tables before importing it into ArcGIS. For this project, the data was divided into two tables, "2018 Increasing 1" and "2018 Increasing 2". The increasing direction was chosen for analysis due to there being more data associated with this direction.

   A unique ID was created for each segment prior to importing the data table into ArcGIS. This is done by combining the route ID and the beginning mile point text. In order to combine the table information with the main roadway ArcGIS file, a "Route Event Layer" was created to join the table data to the roadway segments using the Route ID as a common attribute.

2) Primary Roadway File (2009-2015)

   Roadway information from the TIS system (2009-2015) was located in two files:

   a) An ArcGIS line file that contains basic roadway information in segments, and

b) A table that contains additional information for the roadway segments.

The roadway information is for the entire state, which results in a very large data table (68 columns, 300,000+ rows), and thus it became necessary to divide the table into several smaller tables before importing it into ArcGIS. For this project, the data was divided into three tables, "2012 Increasing 1", "2012 Increasing 2", and "2012 Increasing 3". The increasing direction was chosen for analysis because the 2012 HPMS Routes segments were coded for increasing.

One additional step that was necessary was to rename the Route ID in the data table to match the LRS format. The ArcGIS line files were converted from TIS to LRS Route ID format (increasing) for each segment. To covert from TIS to LRS, a zero was added to the beginning and a "-I" was added to the end of the Route ID. In order to combine the table information with the main roadway ArcGIS file, a "Route Event Layer" was created to join the table data to the roadway segments using the Route ID as a common attribute.

B.3 VOLUME FILES

The volume data from 2009-2018 was obtained from two files:

a) The yearly AADT volume ArcGIS line file[3], and
b) An Access database that contains historical AADT volumes.

The information from the Access database is converted to an Excel pivot table that can be imported into ArcGIS. The yearly AADT volume file is joined to the data table from the Access database using a common sequence number.

In order to eliminate join issues near intersections with the roadway file, the modified volume file was intersected with the study segment file prior to any spatial joins. This eliminated any AADT values from cross streets and roadways not associated with the study.

B.4 SPEED STUDY FILES

The speed study data was located in two files:

a) An ArcGIS line file that contains information for each speed study segment, and
b) A table that contains additional information for the study segments (38 columns of data)

In the data table, a unique ID was created for each study segment (this was done by creating a unique number for each study, ex: SS1, SS2, etc.). The speed study segment file was joined to the data table using the section description field.

[3] https://www.dot.state.mn.us/traffic/data/data-products.html#volume

B.5 INTERSECTION FILES

The intersection data was located in an ArcGIS polygon file. The intersection file had polygons with an average radius of 50 feet from the center of the intersection. For this study, we increased the radius to 250 feet to capture the crash area of influence of the intersection. As such a buffer of 200 feet was added to each intersection.

B.6 CURVE FILES

The curve data was located in two files:

a) An ArcGIS line file that contains information for each curve (the district safety plan curve file), and
b) An ArcGIS database file that contains additional information for curves (53 columns of data)

The district safety plan curve file is joined to the database file using the unique curve number. The district safety plan curve file with additional data is spatially joined to the ARCGIS file containing basic roadway information prior to creating route event layers allowing for the curve data to be spatially joined and the curve information to be transferred to the roadway file.

APPENDIX C:
SAFETY PERFORMANCE FUNCTIONS

SPFs were estimated for each of the target crash types and crash severities. The relationship between the crash frequency and the independent variables can be seen in Figure C-1.

$$Crashes = \exp(\alpha + \beta_1 X_1 + \beta_2 X_2 + \_\_\_ + \beta_n X_n)$$

Figure C-1. Equation. Sample Safety Performance Function

Where:

α = intercept,

X = independent (exposure) variables, and

β = coefficient estimates.

SPFs for segments and intersections (both all traffic control types and thru-strop control only) are presented in Tables C-1 – C-9.

Table C-1. SPFs for Segment Crashes

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Run off Road Estimate (S.E.)	Head On Estimate (S.E.)
Intercept	-7.6944 (0.2504)	-7.7534 (0.3785)	-8.3011 (0.5128)	-7.5999 (0.3495)	-12.9927 (0.8857)
AADT	0.8298 (0.0349)	0.6946 (0.0526)	0.7198 (0.072)	0.7512 (0.0495)	1.1863 (0.1216)
AADT/10000	0.2173 (0.0998)	0.4317 (0.1493)	0.0996 (0.2156)	-0.2064 (0.1579)	-0.3413 (0.3243)
Degree of Curvature	0.1191 (0.0064)	0.1202 (0.0081)	0.1232 (0.0093)	0.1318 (0.0076)	0.1224 (0.0221)
Yearly Factor - 2012	-0.1294 (0.0583)	-0.0274 (0.0924)	-0.3313 (0.1206)	-0.2856 (0.0824)	0.4209 (0.1936)
Yearly Factor - 2013	0.0375 (0.0571)	0.043 (0.0914)	-0.2191 (0.1183)	0.0043 (0.0793)	0.2992 (0.1954)
Yearly Factor - 2014	-0.0187 (0.0574)	-0.0539 (0.0925)	-0.2956 (0.1197)	-0.1115 (0.0803)	0.3511 (0.1943)
Yearly Factor - 2015	-0.1199 (0.0603)	-0.0893 (0.0964)	-0.1852 (0.1221)	-0.276 (0.0854)	0.5001 (0.1967)
Yearly Factor - 2016	0.1023 (0.0589)	0.1917 (0.0932)	0.1885 (0.1163)	0.1068 (0.0814)	0.2535 (0.2037)
Yearly Factor - 2017	0.0823 (0.0617)	0.1018 (0.0985)	0.1719 (0.1213)	0.1031 (0.085)	0.0971 (0.2174)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	0.6886 (0.0566)	0.6348 (0.1374)	0.4287 (0.234)	1.0396 (0.1311)	2.772 (0.7143)

Table C-2. SPFs for Intersection Crashes (3-Leg Intersections with No Lighting – All Control Types)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-8.3582 (0.3133)	-10.0722 (0.5813)	-14.2121 (0.5417)	-12.4275 (0.9557)
Major Road AADT	0.83 (0.0198)	0.7921 (0.0299)	1.408 (0.0425)	1.0515 (0.0718)
Yearly Factor - 2012	0.4444 (0.0769)	0.5974 (0.1194)	0.3488 (0.1477)	0.8171 (0.3217)
Yearly Factor - 2013	0.3899 (0.0773)	0.5031 (0.1204)	0.1516 (0.1518)	0.8837 (0.3183)
Yearly Factor - 2014	0.4959 (0.0764)	0.5835 (0.1194)	0.382 (0.1474)	0.7845 (0.3216)
Yearly Factor - 2015	0.4156 (0.0789)	0.5532 (0.1221)	0.365 (0.1503)	0.8351 (0.3265)
Yearly Factor - 2016	-0.1057 (0.0856)	-0.0737 (0.1355)	-0.0061 (0.1599)	0.6474 (0.3359)
Yearly Factor - 2017	-0.0395 (0.0868)	0.0618 (0.1356)	0.1713 (0.159)	0.3981 (0.3529)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)
TCF - Signalized	0.0712 (0.4607)	1.0883 (0.7431)	-0.2552 (0.7868)	0.1517 (1.0849)
TCF - Thru Stop	-0.7353 (0.2552)	0.2332 (0.5077)	-1.25 (0.3678)	-1.7727 (0.6864)
TCF - Thru Yield	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	2.2503 (0.1202)	3.3178 (0.3169)	3.8249 (0.4017)	12.7026 (2.7755)

For Injury (KAB) crashes: Use Injury (KABC) SPF with the crash proportion of Injury (KAB) crashes to Injury (KABC) crashes

For Angle crashes: Use Total crash SPF with the crash proportion of Angle crashes to Total crashes

Note: TCF = Traffic Control Factor; Side Swipe SD = Side Swipe Same Direction

TableC-3. SPFs for Intersection Crashes (3-Leg Intersections with Lighting – All Control Types)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)
Intercept	-28.4855 (0.5572)	-28.9541 (0.8796)	-28.3507 (1.1717)	-29.8209 (1.3349)
Major Road AADT	0.8409 (0.0617)	0.8556 (0.0967)	0.7657 (0.1291)	0.9474 (0.1501)
Yearly Factor - 2012	0.3456 (0.1883)	0.4532 (0.2993)	0.2061 (0.3859)	-0.2473 (0.3928)
Yearly Factor - 2013	0.2588 (0.1892)	0.4431 (0.2987)	-0.2988 (0.4228)	-0.1928 (0.3896)
Yearly Factor - 2014	0.1933 (0.1908)	0.1145 (0.3121)	-0.117 (0.4066)	-0.3989 (0.4032)
Yearly Factor - 2015	0.2518 (0.1939)	0.131 (0.3183)	-0.0058 (0.4075)	-0.4846 (0.4211)
Yearly Factor - 2016	-0.2835 (0.2133)	-0.448 (0.3626)	-0.9136 (0.5191)	-0.139 (0.3971)
Yearly Factor - 2017	-0.145 (0.2115)	-0.0421 (0.3377)	-0.1771 (0.4344)	-0.81 (0.459)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)
TCF - All Way Stop	20.2343 (0.6785)	19.4034 (1.0812)	19.8397 (1.085)	20.0247 (1.2229)
TCF - Signalized	21.3983 (0.2226)	20.2764 (0.3406)	20.167 (0.4276)	20.8635 (0.439)
TCF - Thru Stop	20.3197 (0)	19.5161 (0)	19.1519 (0)	19.4416 (0)
TCF - Thru Yield	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	0.828 (0.1351)	1.0689 (0.3618)	1.0634 (0.7215)	3.1045 (0.9407)

For Rear End crashes: Use Total crash SPF with the crash proportion of Rear End crashes to Total crashes

For Side Swipe SD crashes: Use Total crash SPF with the crash proportion of Side Swipe Same Direction crashes to Total crashes

Note: TCF = Traffic Control Factor; Side Swipe SD = Side Swipe Same Direction

Table C-4. SPFs for Intersection Crashes (4-Leg Intersections with No Lighting – All Control Types)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-8.9471 (0.4158)	-9.5317 (0.5654)	-8.9729 (0.7637)	-9.5805 (0.7541)	16.6375 (0.7017)	-10.2827 (1.001)
Major Road AADT	0.9854 (0.0243)	0.9562 (0.035)	0.8066 (0.0475)	0.89 (0.0448)	1.678 (0.0521)	0.9491 (0.0747)
Yearly Factor - 2012	0.4069 (0.0961)	0.2617 (0.1342)	0.0683 (0.1797)	-0.0332 (0.1714)	0.39 (0.186)	0.4266 (0.3119)
Yearly Factor - 2013	0.3872 (0.0896)	0.2672 (0.1338)	0.2394 (0.1759)	0.1385 (0.1678)	0.2662 (0.1892)	0.0204 (0.3277)
Yearly Factor - 2014	0.4042 (0.0958)	0.2232 (0.1344)	-0.0037 (0.1814)	0.0353 (0.1688)	0.3538 (0.1862)	0.5707 (0.3063)
Yearly Factor - 2015	0.3886 (0.0985)	0.2583 (0.1375)	0.0902 (0.1844)	0.0697 (0.1735)	0.3212 (0.1717)	0.4301 (0.3173)
Yearly Factor - 2016	-0.306 (0.1084)	-0.4366 (0.1542)	-0.2947 (0.1974)	-0.3845 (0.1875)	-0.2309 (0.2098)	-0.4574 (0.3741)
Yearly Factor - 2017	-0.2051 (0.1103)	-0.5416 (0.164)	-0.5589 (0.2178)	-0.3667 (0.194)	0.1547 (0.2028)	0.0113 (0.3516)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
TCF - All Way Stop	0.5065 (0.4055)	0.3574 (0.5532)	0.8176 (0.7056)	1.4185 (0.6923)	0.9587 (0.6442)	-0.7807 (1.0059)
TCF - Signalized	-0.706 (0.3918)	-0.9174 (0.5371)	-1.2075 (0.7856)	-0.5411 (0.7436)	-0.7365 (0.5948)	-0.9277 (0.7784)
TCF - Thru Stop	-0.7635 (0.328)	-0.6838 (0.4283)	-0.6239 (0.5743)	-0.4379 (0.594)	-0.4706 (0.4326)	-1.8209 (0.6208)
TCF - Thru Yield	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	1.6831 (0.1068)	2.3686 (0.2466)	3.6152 (0.5766)	4.6951 (0.5495)	2.2921 (0.27743)	5.0821 (1.5003)

Note: TCF = Traffic Control Factor; Side Swipe SD = Side Swipe Same Direction

Table C-5. SPFs for Intersection Crashes (4-Leg Intersections with Lighting – All Control Types)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-7.2489 (0.46)	-8.0827 (0.6367)	-7.1283 (0.8216)	-6.6416 (0.6544)	-10.9108 (0.8989)	-8.8809 (1.5612)
Major Road AADT	0.7839 (0.0525)	0.7668 (0.0717)	0.5857 (0.0926)	0.6477 (0.0754)	1.0129 (0.101)	0.637 (0.1768)
Yearly Factor - 2012	0.2708 (0.152)	0.4778 (0.2072)	0.4371 (0.2826)	-0.1069 (0.215)	0.1327 (0.2558)	0.3668 (0.4646)
Yearly Factor - 2013	0.3091 (0.1511)	0.4799 (0.2068)	0.2089 (0.2916)	-0.1758 (0.216)	0.1993 (0.2514)	0.4008 (0.4618)
Yearly Factor - 2014	0.1001 (0.1534)	0.2706 (0.2115)	0.1692 (0.2925)	-0.3021 (0.2193)	0.1074 (0.2538)	-0.0708 (0.4881)
Yearly Factor - 2015	0.2189 (0.1553)	0.414 (0.2123)	0.4177 (0.2892)	-0.2141 (0.2234)	0.3081 (0.2529)	-0.1401 (0.5127)
Yearly Factor - 2016	-0.2432 (0.1667)	-0.2879 (0.24)	0.0062 (0.3098)	-0.3854 (0.2317)	-0.231 (0.2761)	-0.5877 (0.5756)
Yearly Factor - 2017	-0.3332 (0.1725)	-0.1697 (0.2393)	-0.121 (0.3254)	-0.3879 (0.237)	-0.4718 (0.2917)	-0.1556 (0.5408)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
TCF - All Way Stop	0.6686 (0.2232)	-0.0216 (0.3483)	-0.0283 (0.4586)	0.0822 (0.3519)	1.1441 (0.3579)	-0.2765 (1.0592)
TCF - Signalized	0.385 (0.1016)	-0.08 (0.1382)	-0.4373 (0.2051)	-0.4674 (0.1659)	1.2658 (0.1571)	0.7098 (0.3147)
TCF - Thru Stop	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	1.1384 (0.1091)	1.0401 (0.1961)	1.5643 (0.4435)	1.7972 (0.2953)	1.5594 (0.2602)	3.6814 (1.553)

Note: TCF = Traffic Control Factor; Side Swipe SD = Side Swipe Same Direction

Table C-6. SPFs for Intersection Crashes (3-Leg Intersections with No Lighting – Thru-Stop only)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-9.1304 (0.1794)	-9.857 (0.2739)	-9.3403 (0.3782)	-12.8323 (0.5333)	-15.4912 (0.3858)	-14.2933 (0.6905)
Major Road AADT	0.8235 (0.0199)	0.7937 (0.03)	0.6538 (0.042)	1.0125 (0.0583)	1.4097 (0.0426)	1.0648 (0.0719)
Yearly Factor - 2012	0.4538 (0.0772)	0.6019 (0.12)	0.3627 (0.1684)	0.3787 (0.2168)	0.3619 (0.1491)	0.7967 (0.3206)
Yearly Factor - 2013	0.3949 (0.0777)	0.5085 (0.121)	0.3159 (0.1692)	0.4593 (0.2147)	0.158 (0.1534)	0.8511 (0.3174)
Yearly Factor - 2014	0.501 (0.0767)	0.5854 (0.12)	0.5259 (0.165)	0.485 (0.2135)	0.3897 (0.149)	0.7831 (0.3196)
Yearly Factor - 2015	0.4227 (0.0792)	0.5597 (0.1226)	0.3634 (0.1718)	0.3334 (0.2226)	0.392 (0.1513)	0.7739 (0.3269)
Yearly Factor - 2016	-0.0988 (0.086)	-0.0705 (0.1361)	0.0405 (0.182)	-0.1277 (0.2437)	0.0218 (0.1607)	0.6456 (0.3338)
Yearly Factor - 2017	-0.0321 (0.0872)	0.0723 (0.1361)	-0.0141 (0.189)	0.0889 (0.2383)	0.1902 (0.1601)	0.3981 (0.3507)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	2.2212 (0.1201)	3.3561 (0.3201)	5.776 (0.8703)	9.2497 (1.5029)	3.7418 (0.4029)	11.6559 (2.6861)

Note: Side Swipe SD = Side Swipe Same Direction

Table C-7. SPFs for Intersection Crashes (3-Leg Intersections with Lighting – Thru-Stop only)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-8.2533 (0.5809)	-9.39 (0.9127)	-9.116 (1.2257)	-10.6489 (1.4661)	-13.4917 (1.1278)	-10.5898 (1.8534)
Major Road AADT	0.8548 (0.0644)	0.8597 (0.1008)	0.7689 (0.1359)	0.9843 (0.1652)	1.2414 (0.1182)	0.8115 (0.2021)
Yearly Factor - 2012	0.3206 (0.1967)	0.3747 (0.3068)	0.1311 (0.3961)	-0.2799 (0.4223)	0.5623 (0.4143)	0.4893 (0.6341)
Yearly Factor - 2013	0.2181 (0.1979)	0.365 (0.306)	-0.4043 (0.4369)	-0.2101 (0.4178)	0.8525 (0.4012)	0.2975 (0.6517)
Yearly Factor - 2014	0.1569 (0.1995)	0.0448 (0.3195)	-0.2532 (0.4227)	-0.4048 (0.4304)	0.4846 (0.4161)	-0.1772 (0.7071)
Yearly Factor - 2015	0.2251 (0.2026)	-0.0053 (0.3302)	-0.1446 (0.4242)	-0.5287 (0.451)	0.8267 (0.4085)	0.4252 (0.6527)
Yearly Factor - 2016	-0.3063 (0.222)	-0.4666 (0.3671)	-0.9339 (0.5249)	-0.1819 (0.4257)	0.662 (0.4376)	-0.93 (0.8964)
Yearly Factor - 2017	-0.2136 (0.2228)	-0.2207 (0.3554)	-0.449 (0.4705)	-1.1344 (0.5287)	0.5428 (0.4296)	-0.8403 (0.8981)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	0.9487 (0.1504)	1.2846 (0.4103)	1.5043 (0.9043)	4.2265 (1.241)	1.7852 (0.5012)	2.8593 (2.2526)

Note: Side Swipe SD = Side Swipe Same Direction

Table C-8. SPFs for Intersection Crashes (4-Leg Intersections with No Lighting – Thru-Stop only)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-9.702 (0.2193)	-10.1426 (0.3161)	-9.5226 (0.4247)	-10.0429 (0.3989)	-17.1076 (0.4935)	-12.0755 (0.7073)
Major Road AADT	0.9845 (0.0246)	0.9475 (0.0356)	0.7983 (0.0483)	0.8926 (0.0458)	1.6817 (0.0531)	0.9469 (0.0776)
Yearly Factor - 2012	0.4028 (0.0979)	0.2554 (0.1368)	0.0537 (0.1832)	-0.0338 (0.1758)	0.3636 (0.1891)	0.3878 (0.3265)
Yearly Factor - 2013	0.3846 (0.0978)	0.2659 (0.1363)	0.2278 (0.1792)	0.1367 (0.1722)	0.2319 (0.1922)	0.0311 (0.3408)
Yearly Factor - 2014	0.4083 (0.0975)	0.2244 (0.1368)	0.0048 (0.1842)	0.0421 (0.1733)	0.3329 (0.1888)	0.5565 (0.3205)
Yearly Factor - 2015	0.3854 (0.1004)	0.258 (0.1402)	0.0857 (0.1879)	0.0721 (0.1784)	0.2745 (0.1952)	0.3821 (0.3327)
Yearly Factor - 2016	-0.3034 (0.1103)	-0.4453 (0.1573)	-0.3014 (0.201)	-0.3514 (0.1911)	-0.2766 (0.2142)	-0.4052 (0.3842)
Yearly Factor - 2017	-0.2138 (0.1125)	-0.5467 (0.1673)	-0.5897 (0.2234)	-0.379 (0.1999)	0.1354 (0.2061)	0.0409 (0.363)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	1.7553 (0.1119)	2.5486 (0.2635)	3.9717 (0.6266)	5.0701 (0.5943)	2.4286 (0.2952)	6.9402 (1.9785)

Note: Side Swipe SD = Side Swipe Same Direction

Table C-9. SPFs for Intersection Crashes (4-Leg Intersections with Lighting – Thru-Stop only)

Parameter	Total Estimate (S.E.)	Injury (KABC) Estimate (S.E.)	Injury (KAB) Estimate (S.E.)	Angle Estimate (S.E.)	Rear End Estimate (S.E.)	Side Swipe SD Estimate (S.E.)
Intercept	-7.2539 (0.5263)	-7.9057 (0.6857)	-7.0883 (0.8572)	-6.8585 (0.7087)	-9.6524 (1.1591)	-7.8403 (1.8173)
Major Road AADT	0.7991 (0.06)	0.7722 (0.0771)	0.6152 (0.0968)	0.681 (0.0812)	0.9047 (0.1315)	0.5436 (0.2047)
Yearly Factor - 2012	0.1692 (0.1859)	0.2101 (0.2308)	0.1325 (0.291)	-0.2066 (0.2452)	-0.2131 (0.382)	0.0814 (0.5917)
Yearly Factor - 2013	0.137 (0.1869)	0.2077 (0.2311)	-0.042 (0.2996)	0.2241 (0.2445)	-0.3517 (0.954)	-0.124 (0.614)
Yearly Factor - 2014	-0.1155 (0.1911)	0.0169 (0.2364)	-0.1815 (0.3058)	-0.4818 (0.2537)	-0.4339 (0.989)	-0.8755 (0.7051)
Yearly Factor - 2015	-0.0125 (0.1936)	0.0736 (0.241)	-0.0772 (0.309)	-0.376 (0.2581)	-0.0624 (0.3811)	-0.4925 (0.6725)
Yearly Factor - 2016	-0.2581 (0.2025)	-0.3513 (0.2629)	-0.2218 (0.3208)	-0.2695 (0.2566)	-0.4627 (0.4108)	-0.4315 (0.6744)
Yearly Factor - 2017	-0.3282 (0.2105)	-0.3255 (0.2694)	-0.3382 (0.3389)	-0.3947 (0.2682)	-0.6379 (0.4399)	0.0698 (0.6374)
Yearly Factor - 2018	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dispersion	1.3651 (0.1613)	0.9274 (0.2296)	1.1688 (0.439)	1.8666 (0.3402)	4.195 (1.057)	6.6212 (3.7009)

Note: Side Swipe SD = Side Swipe Same Direction

APPENDIX D:
ANNUAL CALIBRATION FACTORS

The SPFs presented in Appendix C were used to estimate annual calibration factors (ACFs). The ACFs are defined as the ratio of the total observed crash frequency to the total predicted crash frequency from the SPF, and are calculated for each year. The ACFs are estimated to account for time trends. The ACFs are presented in Tables D-1 – D-9.

Table D-1. ACFs for Segment Crashes

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.985	0.981	0.992	0.981	0.988	0.985	0.985
Injury (KABC)	0.993	0.995	0.998	0.991	0.996	0.995	0.996
Injury (KAB)	0.999	0.998	0.998	0.997	0.998	0.996	0.995
Run off Road	0.989	0.981	0.989	0.989	0.986	0.982	0.980
Head On	0.989	1.001	0.996	0.984	1.003	0.995	1.009

Table D-2. ACFs for Intersection Crashes (3-Leg Intersections with No Lighting – All Control Types)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.999	1.002	1.008	1.002	1.017	1.024	0.992
Injury (KABC)	0.986	1.004	0.991	1.012	1.014	1.003	0.994
Rear End	0.982	0.982	0.960	0.977	1.002	0.969	0.920
SSSD	1.004	1.028	1.026	0.994	0.982	1.026	1.010

For Injury (KAB) crashes: Use Injury (KABC) crash ACFs
For Angle crashes: Use Total crash ACFs
Note: SSSD = Side Swipe Same Direction

Table D-3. ACFs for Intersection Crashes (3-Leg Intersections with Lighting – All Control Types)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.959	0.999	0.996	0.989	0.957	1.004	0.929
Injury (KABC)	0.966	0.991	1.015	1.008	0.965	0.998	0.919
Injury (KAB)	0.976	0.996	1.020	1.015	0.981	1.017	0.947
Angle	0.965	0.952	0.954	0.959	0.940	1.081	0.854

For Rear End crashes: Use Total crash ACFs
For Side Swipe SD crashes: Use Total crash ACFs
Note: SSSD = Side Swipe Same Direction

Table D-4. ACFs for Intersection Crashes (4-Leg Intersections with No Lighting – All Control Types)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	1.000	1.002	1.017	1.023	1.021	1.040	0.980
Injury (KABC)	1.002	1.010	1.000	1.015	1.006	0.997	0.966
Injury (KAB)	1.000	0.997	0.982	1.010	1.008	0.995	0.993
Angle	0.982	0.986	1.035	1.038	1.006	1.007	0.961
Rear End	1.013	0.893	0.966	0.964	0.933	0.912	0.797
SSSD	1.002	1.017	1.056	1.032	0.981	0.980	1.042

Note: SSSD = Side Swipe Same Direction

Table D-5. ACFs for Intersection Crashes (4-Leg Intersections with Lighting – All Control Types)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.990	1.038	1.079	1.044	0.939	0.965	0.922
Injury (KABC)	1.002	1.012	1.021	1.009	0.988	1.000	0.971
Injury (KAB)	1.009	0.995	1.005	0.997	1.003	1.000	1.005
Angle	0.984	1.010	1.023	0.997	1.000	1.024	0.966
Rear End	1.008	1.134	1.119	1.070	0.924	0.988	0.873
SSSD	1.011	1.025	1.117	1.014	0.973	0.910	0.999

Note: SSSD = Side Swipe Same Direction

Table D-6. ACFs for Intersection Crashes (3-Leg Intersections with No Lighting – Thru-Stop only)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.999	1.001	1.008	1.004	1.020	1.027	0.991
Injury (KABC)	0.986	1.003	0.991	1.012	1.015	1.003	0.995
Injury (KAB)	0.992	0.996	0.986	1.009	1.019	1.009	1.004
Angle	0.983	0.976	1.000	0.993	0.969	0.979	0.980
Rear End	0.983	0.978	0.955	0.985	1.010	0.979	0.916
SSSD	0.995	1.036	1.041	0.998	0.996	1.040	1.022

Note: SSSD = Side Swipe Same Direction

Table D-7. ACFs for Intersection Crashes (3-Leg Intersections with Lighting – Thru-Stop only)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.959	0.993	0.997	0.977	0.968	0.993	0.940
Injury (KABC)	0.966	0.991	1.014	0.991	0.969	0.978	0.919
Injury (KAB)	0.988	1.006	1.007	1.000	0.982	0.991	0.948
Angle	0.932	0.911	0.930	0.917	0.951	1.034	0.887
Rear End	0.945	0.953	1.010	0.925	0.911	0.945	0.991
SSSD	1.039	1.000	1.003	0.970	0.978	0.975	0.941

Note: SSSD = Side Swipe Same Direction

Table D-8. ACFs for Intersection Crashes (4-Leg Intersections with No Lighting – Thru-Stop only)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	0.994	1.001	1.007	1.014	1.032	1.029	0.962
Injury (KABC)	0.992	1.005	1.002	1.003	1.016	0.991	0.965
Injury (KAB)	0.994	0.996	0.987	0.993	1.014	0.986	0.997
Angle	0.989	0.988	1.027	1.017	1.024	0.982	0.925
Rear End	0.999	0.881	0.952	0.949	0.935	0.876	0.785
SSSD	0.994	1.007	0.987	1.062	1.014	1.026	0.949

Note: SSSD = Side Swipe Same Direction

Table D-9. ACFs for Intersection Crashes (4-Leg Intersections with Lighting – Thru-Stop only)

Crash Type	ACF 2012	ACF 2013	ACF 2014	ACF 2015	ACF 2016	ACF 2017	ACF 2018
Total	1.008	0.988	1.012	1.050	1.007	1.006	0.953
Injury (KABC)	1.007	0.991	1.010	1.008	1.003	0.994	0.993
Injury (KAB)	1.008	0.992	1.001	1.005	1.003	1.001	1.007
Angle	0.981	1.010	1.011	1.005	1.002	1.041	0.972
Rear End	1.021	0.943	0.969	1.151	1.071	1.017	0.974
SSSD	0.996	0.975	1.029	1.011	0.995	0.951	1.073

Note: SSSD = Side Swipe Same Direction