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Reducing Crashes at Controlled Rural Intersections



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Executive Summary

0.1 Introduction

This report is the culmination of a project intended to provide an initial exploration into ways to reduce crashes by manipulating the infrastructure present at rural controlled intersections. This project had two parts. The first part, conducted by Mr. Howard Preston, a consulting transportation engineer, investigated Minnesota Department of Transportation (Mn/DOT) crash records databases in order to understand the characteristics of crashes at rural intersections. A field analysis of the physical characteristics present at problem intersections was also performed. The work completed by Mr. Preston can be found in Appendix A.

The second part of the project, conducted by Dr. Kathleen Harder and Dr. John Bloomfield of the University of Minnesota, built on the crash records database analysis and the field analysis. First, a focus group was held to identify creative and innovative ways to improve safety at controlled rural intersections. The focus group was instrumental in identifying a particular problem intersection in Goodhue County, Minnesota. This intersection became the subject of a Human Factors review and analysis and subsequently a preliminary experiment was conducted. The rural intersection in Goodhue County was used as a model to test possible mitigating strategies that might be used with other problem rural intersections across Minnesota. This experiment and the recommendations generated by it are described in the main body of this report. The intent of the project was to provide the groundwork for future research focused on reducing crashes at rural controlled intersections.

The objective of the simulation experiment described in this report was to:

- Determine the effect of modifications made to increase the saliency of a rural Thru-STOP intersection on the behavior of drivers as they approached the intersection on the major and minor roads.

The problem at rural Thru-STOP intersections can be seen in an analysis of Mn/DOT's crash databases, for Minnesota in 1998, 1999, and the first half of 2000 (1). Thirty-six percent of the 2,296 crashes considered were right-angle crashes—more than twice the number of any other crash type (1). Right-angle crashes were still further over-represented when crash severity was considered. They accounted for 71% (34/48) of fatal crashes, 62% (48/77) of crashes involving severe injuries and 48% (444/920) of crashes involving property damage (1).

The current study focused on a problem intersection located in Goodhue County, Minnesota. At this intersection, the North-South road is Trunk Highway 58 (TH-58), and the East-West road is County Road 9 (CR-9). There are stop signs on CR-9, but none on TH-58.

Using a driving simulator, we investigated the effect of a number of interventions that were intended to increase the saliency of the intersection. The following interventions were tested:

- Adding traffic islands on CR-9.
- Using two stop signs instead of one on each of both approaches (an approach from the East and one from the West) on CR-9.
- Using reflective posts for the stop signs on CR-9.
- Improving the sight lines for drivers stopped on the East side of CR-9 and looking at the traffic approaching the intersection from the North on TH-58, by removing foliage on the Northeast side of the intersection.
- Adding innovative signage—two large guide signs [4.2 meters (13.8 ft) wide by 1.3 meters (4.3 ft) high]—to make the intersection more salient to drivers on TH-58.

- Providing earlier warnings of the intersection to drivers on TH-58.

The first four of these interventions were aimed at making the intersection more salient for the drivers on CR-9, while the last two were intended to make drivers on TH-58 more aware of the approaching intersection.

0.2. Method—Driving Simulator Experiment

The study participants (25 males and 24 females) were licensed drivers between 18 and 65. In the experimental sessions, each participant drove in an advanced driving simulator with a 210-degree forward field-of-view. The driving simulator also provides rear-view imagery, via the simulator vehicle's rear view mirror (which reflects imagery from an additional screen) and via two 5-inch LCD screens installed in place of the vehicle's side-view mirrors. The vehicle's controls are equipped with sensors that relay driver inputs to the steering wheel, transmission, and the accelerator and brake pedals to the simulation computer, which provides a real-time interface with the virtual environment. Road and traffic noise, and vehicle engine sounds are delivered through four speakers placed near the base of the forward screen. The virtual position of the simulator vehicle relative to the scenario being driven was recorded at 20 Hz, allowing us to determine vehicle speed and position.

The participants were divided into two groups: A Before Condition Group and an After Condition Group. Both groups drove four times, approaching the intersection once from the North, the East, the South, and the West. The order in which they approached the intersection was counterbalanced across participants. Those in the Before Condition drove with the intersection modeled as it currently exists in the real world, while the participants in the After Condition drove with the interventions added to the intersection.

0.3 Results

0.3.1 Approaching the Intersection on CR-9—The interventions affected the distance before the intersection at which the participants began to reduce speed. On the approach from the West this distance increased significantly from 236.6 meters (776.2 ft) in the Before Condition to 301.4 meters (988.8 ft) in the After Condition. On the approach from the East, in the After Condition the stopping distance was reduced and the distance at which the participants began to reduce speed increased, but these changes were smaller than on the approach from the West and were not statistically significant.

0.3.2 Approaching the Intersection on TH-58—The interventions also affected the participants when they were driving on TH-58. On the approach from the North, 20% of the participants in the After Condition reduced their speed over the last 100 meters (328 ft) before the intersection by an average of 44%. And on the approach from the South, all the participants in the After Condition reduced their speed by an average of 11.8%.

0.4. Discussion

0.4.1 Approaching the Intersection on the Minor Road—The interventions implemented in this simulation experiment affected the driving behavior of the participants in the following ways:

- The participants began to reduce speed further away from the intersection. The implication of this effect is that, by starting to slow down further away from the intersection, a driver will be able to execute a more controlled stop and, as a result, will be less likely to inadvertently run the stop sign.
- Further, making the intersection more noticeable may make it easier for a driver to stop at a point where he or she can see better. From this closer position, the driver may have a better view of the crossing road and this, in turn, may reduce the likelihood of the driver pulling out into the space

in front of an approaching vehicle on the cross road that is insufficient to allow safe access to the road.

0.4.2 Approaching the Intersection on the Major Road—The interventions implemented in this experiment resulted in the participants slowing down as they approached the intersection on the major road.

- Twenty percent of the participants in the After Condition who approached the intersection from the North, reduced their speed by an average of 44% (40/90). A 44% reduction in the speed of a driver approaching the intersection would have a very large effect on emergency braking performance. If a vehicle pulled into the intersection from the minor road, necessitating an emergency braking maneuver by the vehicle on the major road, then a 44% speed reduction would produce a 60% (40.5/67) reduction in the stopping distance, making it far less likely that a right-angle crash would occur.
- The participants in the After Condition who approached the intersection from the South reduced their speed by an average of 11.8% (11/93.5). With this reduction in speed, if a vehicle pulled into the intersection from the minor road, a driver in the major road would have an 18.4% (13.2/71.8) reduction in stopping distance. As a result, he or she would be less likely to be involved in a right-angle crash. And if a crash could not be avoided, it is likely that its severity would be reduced.

0.4.3 Reaction Time—In estimating stopping distance, we assumed that the driver would have a reaction time of 1 second. There is evidence suggesting the participants in the After Condition might have reaction times as short as 500 ms (4). If their reaction time were this short, then the reduction in the stopping distances would be larger—increasing from 60% to 71% (47.5/67) for 20% of participants approaching from the North, and from 18.4% to 34.4% (24.7/71.8) for the participants in the After Condition on the approach from the South

These results suggest that the interventions tested in the simulation experiment are promising and would be worth investigating in a field test. The interventions investigated in this project would likely be useful at other rural controlled intersections with sight-limited intersections, particularly those at which the minor road is more important than the gravel roads encountered at previous intersections. However, unlike the intersection of TH-58 and CR-9, not all rural intersections with similar problems have the light posts required for hanging the signage on the major road. Further analysis should be conducted at other rural controlled intersections to determine other interventions that might be appropriate at them. There will likely not be a single optimal solution that will fit all problem rural controlled intersections.

Future work could involve categorizing rural intersections with regard to:

- the horizontal cross-angles of the intersection
- vertical curves
- relative position of vegetation and buildings
- relative position of commercial and highway signage
- presence of lighting

Following the categorization process, possible mitigating strategies to modify the infrastructure would be developed.

References

1. H. Preston and T. Jensen (2001). Rural Intersection Crash Study. Draft Technical Memo to Technical Advisory Panel for Mn/DOT Agreement No.: 74708, Work Order No.: 175.

Chapter 1

Introduction

1.1 Project Overview

This report is the culmination of a project intended to provide an initial exploration into ways to reduce crashes by manipulating the infrastructure present at rural controlled intersections. This project had two parts. The first part, conducted by Mr. Howard Preston, a consulting transportation engineer, investigated Minnesota Department of Transportation (Mn/DOT) crash records databases in order to understand the characteristics of crashes at rural intersections. A field analysis of the physical characteristics present at problem intersections was also performed. The work completed by Mr. Preston can be found in Appendix A.

The second part of the project, conducted by Dr. Kathleen Harder and Dr. John Bloomfield at the University of Minnesota, built on the crash records database analysis and the field analysis. First, a focus group was held to identify creative and innovative ways to improve safety at controlled rural intersections. The focus group was instrumental in identifying a particular problem intersection in Goodhue County, Minnesota. This intersection became the subject of a Human Factors review and analysis and subsequently a preliminary experiment was conducted. The rural intersection in Goodhue County was used as a model to test possible mitigating strategies that might be used with other problem rural intersections across Minnesota. This experiment and the recommendations generated by it are described in the main body of this report.

The intent of the project was to provide the groundwork for future research focused on reducing crashes at rural controlled intersections.

1.2 Background

1.2.1 Introduction—This project was conducted in response to a call by Mn/DOT and the Local Road Research Board (LRRB) (conveyed to us by Allen Forsberg, Chief Highway Engineer of Blue Earth County, Minnesota), for innovative research on ways to improve safety at rural Thru-STOP intersections.

1.2.2 Rural Crash Types—The problem at rural Thru-STOP intersections is indicated in the analysis conducted, as a part of this project, by Preston, of Mn/DOT's crash databases for Minnesota in 1998, 1999, and the first half of 2000 (1). Preston analyzed 2,296 crashes that occurred at 1,604 intersections in that 2.5-year period (1). Their breakdown of crash types is presented in Table 1.1 below.

Table 1.1. Crash Distribution Types of 2,296 Thru-STOP Crashes—adapted from Preston (1, page 2)

Crash Type	Percentage
Rear end	17%
Sideswipe—same direction	5%
Left turn into oncoming traffic	4%
Run-off the road	13%
Right angle	36%
Right turn into oncoming traffic	0%
Head-on	3%
Sideswipe—opposite direction	2%
Other or unknown	20%
Total	100%

1.2.3 Right-Angle Crashes—The table shows that 36% of the crashes were right-angle crashes. This was more than twice as many as the next largest contributor, rear-end crashes (accounting for 17%), and almost three times the third largest contributor, run-off-the-road crashes (13%). No other crash type exceeded 5%—except for those crashes classified as other or unknown and for which insufficient information was available.

Not only are right-angle crashes the most prevalent type of Thru-STOP crash, but they are also further over-represented when the severity of Thru-STOP crashes is considered. Preston found that, in the 1998-mid 2000 test period, right-angle crashes accounted for 71% (34/48) of the fatal crashes, 62% (48/77) of the crashes involving severe injuries and 48% (444/920) of those involving property damage (1).

1.2.4 Factors Contributing to Right-Angle Crashes Derived from Crash Analysis

—Preston analyzed the behavior of the driver on the minor road on encountering the stop sign (1). They assigned it to one of the following three categories—

- Category 1—The driver stopped at the stop sign, and then pulled out.
- Category 2—The driver ran the stop sign.
- Category 3—Unknown/Other—this categorization was used when the examining officer could not assign the behavior to Category 1 or Category 2, *and* the driver’s reports were conflicting or unclear.

The results of this categorization procedure are presented in Table 1.2.

Table 1.2. Stopping Behavior at 768 Right-Angle Crashes—derived from Preston (1, page 5)

Stopping Behavior	Percentage
Category 1—Stopped, then pulled out	56.6%
Category 2—Ran stop sign	26.6%
Category 3—Unknown/Other	16.8%
Total	100%

Preston also suggests that the age of the driver on the minor road may contribute to crashes at a Thru-STOP (1). For two groups—young drivers (who are 19 and under), and very elderly drivers (who are 85 and older)—the proportion who stop and then pull out and are involved in a crash is much higher than their proportionate involvement in all crash types.

1.2.5 Additional Possible Contributing Factor: Higher Speed Differentials between Vehicles Involved in Crashes—The major-minor intersections often have neither traffic lights, nor stop signs for the trunk highway traffic over long distances. Because of this, traffic on the trunk highways travels at relatively high speeds while traffic on the minor roads should stop at Thru-STOPS. As a result of these factors, there may be problems when trunk highways intersect with minor roads because the drivers traveling on the trunk highways do not expect to encounter crossing traffic at the rural intersections. And if they do encounter crossing traffic it will be traveling relatively slowly. The problems will be greater at intersections with poor sight-lines for traffic on both the major and minor roads.

1.3 Current Study

1.3.1 The Selected Intersection—This study focused on a particular problem rural intersection in Goodhue County, Minnesota. The North-South road is Trunk Highway 58 (TH-58), and the East-West road is County Road 9 (CR-9). There are stop signs on CR-9, but none on TH-58.

This intersection was discussed in a focus group meeting that was held in the Fall of 2001. Because this discussion suggested that the Goodhue County intersection was likely to be of particular interest, Harder and Bloomfield traveled to Goodhue County and examined the intersection carefully. The Human Factors review of the intersection revealed that the sight-lines are a problem for drivers on CR-9, particularly for those stopped on the east side of the intersection and for drivers approaching the intersection on TH-58, particularly from the north. After the Human Factors examination, there appeared to be several ways in which the intersection of these roads could be made more salient to drivers on both CR-9 and TH-58.

1.3.2 Interventions—The simulation experiment conducted for this study tested the following interventions:

- Adding traffic islands on CR-9.
- Using two stop signs instead of one on each of the approaches (from the East and West) on CR-9.
- Using reflective posts for the stop signs on CR-9.
- Improving the sight lines for drivers stopped on the East side of CR-9 and looking at the traffic approaching the intersection from the North on TH-58, by removing foliage on the Northeast side of the intersection.
- Adding innovative signage—two large guide signs [4.2 meters (13.8 ft) wide by 1.3 meters (4.3 ft) high]—to make the intersection more salient to drivers on TH-58.
- Providing earlier warnings of the intersection to drivers on TH-58.

1.3.3. The Potential Effect of Interventions on Drivers on the Minor Road—The first four of these interventions were aimed at making the intersection more salient for the drivers on CR-9, the minor road crossing the intersection. The motivation for making the intersection more salient to drivers on CR-9 was to make them aware that the intersection is with a major road and therefore should be taken seriously (i.e., drivers on the minor road should carefully evaluate the speed of the approaching traffic on TH-58). In order to determine whether the interventions that were implemented for the After Condition were effective, the following driving behaviors were investigated.

- First, did the driver reduce speed earlier? If the saliency of the intersection is increased, then it should be visible from further away and this, in turn, should allow the driver to reduce speed earlier and execute a more controlled stop.
- Second, were there any instances of running the stop sign? Increasing the saliency of the intersection should make it less likely that a driver would run through the stop sign.

Further, increasing the saliency of the intersection may make it easier for a driver to stop at a point where he or she can see better. From this closer position, the driver may have a better view of the crossing road and this, in turn, may reduce the likelihood of the driver pulling out into the space in front of a vehicle on the crossing road that is insufficient to allow safe access to the road.

1.3.4 The Potential Effect of Interventions on Drivers on the Major Road— The fifth and sixth interventions address the issue of higher speed differentials on the major roads. It should be noted that, while one causal factor in Thru-STOP crashes is that the driver on the minor road has moved into the intersection, there may be other contributing factors relating to the major road or to the driver on the major road. These potentially contributing factors include the following:

- (i) There may be problems with the approach to the Thru-STOP intersections on the major road [i.e., the intersection may be obscured because of the road geometry (bends and/or hills), and/or by buildings, and/or by foliage]. If the intersection is obscured, a driver on the major road may have insufficient time to slow down and avoid a right-angle crash if a vehicle on the minor road has driven into the intersection.
- (ii) The speed limit on the major road as the intersection is approached may be inappropriate. In this case, a driver on the major road who is driving at the speed limit may be traveling too fast, and may be unable to slow down quickly enough to avoid a right angle crash with a vehicle which has driven into the intersection from the minor road.
- (iii) Even if the major road speed limit on the approach to the intersection is appropriate, the driver may be driving faster than the speed limit. Again in this case, a driver on the major road may be traveling so fast that he or she is unable to slow down quickly enough to avoid a right angle crash with a vehicle which has driven into the intersection from the minor road.

To determine whether the interventions implemented for the After Condition were effective in changing the behavior of the participants when they were traveling on TH-58, the analysis will focus on whether the After Condition produced reductions in speed on the approaches to the intersection from the North and South when compared to the Before Condition.

Chapter 2 Method

2.1 Participants

Participants were licensed drivers between the ages of 18 and 65. Twenty-five males and 24 females participated in the experiment. Participants were paid \$15 upon completion of their experimental session.

2.2 Driving Simulator

Participants drove in the advanced driving simulator in the University of Minnesota's HumanFIRST laboratory. Key components of this simulator are described below:

2.2.1 Simulator Vehicle—The simulator vehicle was a full-body 2002 Saturn SC1 coupe.

2.2.2 Simulator Visuals—The driver of the simulator vehicle had a 210-degree forward field-of-view. This 210-degree forward field of view was provided by five flat-panel screens—each of which measured 4.7-ft high and 6.5-ft-wide. There was a central flat panel in front of the simulator vehicle. The center of this panel was aligned with the line of sight of the driver of the simulator vehicle. Two intermediate panels flanked this central panel, with one on the left and one on the right. They were set at 138-degrees to the central panel. Finally, there were two outer panels—again, one to the right, the other to the left—set at 138-degrees to the intermediate panels. All five flat-panel screens were elevated 16 inches from the ground. Five projectors were used to project a coordinated, high fidelity, virtual environment onto the five flat-panels comprising the 210-degree forward field-of-view. The simulator also provided rear-view imagery, via an additional 10-ft high by 7.5-ft wide rear-view screen and two 5-inch LCD screens installed in the place of the simulator vehicle's side-view mirrors.

2.2.3 Simulator Vehicle Controls—The simulator vehicle's controls were equipped with sensors that relayed the participant's inputs to the steering wheel, transmission, and accelerator and brake pedals to the driving simulator computer. This provided a real-time interface with the virtual environment. Force feedback was applied to the steering wheel using a high-torque motor attached to the steering column. A vacuum assist pump was connected to the brake pedal in order to simulate realistic braking. The simulator vehicle was equipped with an automatic transmission interface, which was functional and was controlled by the simulator computer.

2.2.4 Simulator Sound System—Road and traffic noise, and the simulator vehicle's engine sounds were delivered through four speakers placed around the car's exterior near the base of the forward screen. Each speaker received independent inputs from the simulator's 3D sound generation system. Low frequencies were delivered using a ten-inch subwoofer placed inside the simulator vehicle's engine compartment. Recorded instructions were also delivered through the four speakers placed at the base of the forward screen. In addition, during the experimental session, the experimenter could communicate with the participant via a dedicated intercom

system that made use of four speakers that were installed in the simulator vehicle's factory speaker locations.

2.2.5 Simulator Vehicle Movement—A bass shaker mounted to the underside of the car's frame provided additional low-frequency vibration. Servo-motors attached to the suspension components at each of the rear tires provided a partial motion base.

2.2.5 Data Recording—The virtual position of the simulator vehicle, relative to the scenario that the participant was driving, was recorded, at 20 Hz, throughout each experiment drive. From this record, it was possible to determine the participant's steering performance and speed of the vehicle. In addition, three micro-video cameras positioned in the cab of the simulator vehicle were used to record (i) the participant's face, (ii) his or her foot position, and (iii) his or her steering wheel response throughout the course of the experimental session. A video display at the experimenter's station enabled the experimenter to monitor the participant throughout each session.

2.3 Experimental Design

Each participant drove four separate times through a Thru-STOP intersection modeled after the intersection of TH-58 and CR-9 in Goodhue County, Minnesota. Participants drove through the intersection once on the approaches from the North, the East, the South, and the West. The order in which they drove the approaches was counterbalanced across participants. The intersection was modeled twice:

1. A Before Condition, with the intersection modeled as it currently exists in the real world.
2. An After Condition, with the following modifications made to the intersection:
 - Traffic islands added on CR-9.
 - Using two stop signs instead of one on each of the approaches (from the East and West) on CR-9.
 - Reflective posts for the stop signs on CR-9.
 - Improved the sight lines for drivers stopped on the East side of CR-9 and looking at the traffic approaching the intersection from the North on TH-58, by removing foliage on the North-East side of the intersection.
 - Innovative signage added to make the intersection more salient to drivers on TH-58.
 - Earlier warnings of the intersection provided to drivers on TH-58.

Half of the participants drove through the intersection four times in the Before Condition; while the other half drove through it four times in the After Condition.

2.4 Driving Scenarios

2.4.1 Practice Drive— The practice drive took place on a segment of two-lane undivided highway. A four-way stop-controlled intersection occurred shortly after the start of the practice drive. This was to provide stopping practice—the skill of stopping at a specific point on the roadway needs to be practiced for each particular vehicle an individual may drive, and in the current experiment, the participants needed to stop at a controlled intersection. The posted speed limit in the practice drive was 55 mph.

2.4.2 *Before Condition*—Twenty-four of the participants drove in the Before Condition with the intersection of TH-58 and CR-9 modeled as it currently exists. TH-58, the through-road is a two-lane undivided highway running North-South, with a posted speed limit of 55 mph. There are left- and right-turn lanes at the intersection with CR-9 on each approach to the intersection. CR-9, the stop-controlled road is a two-lane undivided road running East-West, also with a posted speed limit of 55 mph. However on CR-9, there are no turn lanes on either approach to the intersection.

The plan-view of the intersection, shown in Figure 2.1 below, shows that the two roads are not perpendicular to each other.



Figure 2.1. Plan-view of Goodhue County Intersection [The intersection is in the darker green area in the lower right quadrant of the figure.]

In Figure 2.1, the intersection of CR-9 and TH-58 is in the darker green area in the lower right quadrant of the figure. CR-9 is the East-West road. TH-58 is the North-South road—although as

it runs through the Goodhue County intersection, it goes from the North Northwest to the South Southeast. The angle for the Northeast and Southwest corners is 74 degrees, and the angle for the Southeast and Northwest corners is 106 degrees.

In addition, approaches to the intersection from the North, East, and West are all negatively graded, while the approach from the South is level. The vegetation in the scenario for the Before Condition was modeled to resemble the actual vegetation at the real intersection.

On the approach from the North, approximately 500 meters (1,640 ft) before the intersection, the road bends to the left. There are some large trees to the left (East) of TH-58 where the bend occurs. Also at this bend, but on the right (West) side, there is a T-junction and the minor road approaching from the West at this point is stop-controlled.

The intersection has two lampposts—one in the Northeast quadrant of the intersection and one in the Southwest quadrant of the intersection. There are also regulatory and guide signs at the intersection. On TH-58, in addition to the pavement markings associated with the turning lanes, the approaches to the intersection from the North and South have signs giving the name of the crossroad (County 9). Figure 2.2 is the simulated view of the intersection seen by the driver approaching it from the North.



Figure 2.2. Before Condition—the Simulated Intersection Viewed from the North (Facing South) on TH-58

The approaches from the East and West are stop-controlled. These approaches each have a standard stop sign with a “cross traffic does not stop” underbar. The stop sign and underbar are mounted on a pair of white poles positioned on the right side of the roadway. Figure 2.3 shows the view of the simulated intersection from the East on CR-9.



Figure 2.3. Before Condition—the Simulated Intersection Viewed from the East (Facing West) on CR-9

Participants started each drive several miles away from the intersection; the distance traveled was different for each approach. The distances driven for each approach are given in Table 2.1. During each approach, an oncoming vehicle passed the participant near the beginning of the drive, before the intersection was in sight.

Table 2.1. Distance Traveled on Each Approach to the Intersection

Approach	Distance traveled
From North (on Th-58)	4.6 km (2.86 miles)
From East (on CR-9)	2.8 km (1.74 miles)
From South (on Th-58)	3.5 km (2.17 miles)
From West (on CR-9)	2.8 km (1.74 miles)

2.4.3 *After Condition*—Twenty-five participants drove through the intersection with it modified to provide the After Condition. The intersection angles and gradations of the approaches were unchanged. The speed limits on the four approaches, and the distance that the participants traveled on each approach (given in Table 2.1) were also unchanged.

However, several additional modifications to the intersection were made in the After Condition. On TH-58, approximately 500 meters (1640 ft) before the intersection on the approaches from both the North and South, signs were placed to indicate the intersection ahead. On the approach from the North, this sign appeared just before the T-junction.

In addition, two large road guide signs were hung from the lampposts at the intersection. Although they were guide signs—indicating the presence of CR-9—we hoped that because of their size they would warn drivers on TH-58 that there was a crossing road ahead. The signs were 4.2 meters (13.8 ft) wide and 1.3 meters (4.3 ft) high, and they were hung 6.5 meters (21.3 ft) above the roadway.

A view of the simulated intersection in the After Condition from the North can be seen in Figure 2.4.



Figure 2.4. After Condition—the Intersection Viewed from the North (Facing South) on TH-58

For the After Condition, CR-9 was widened near the intersection to accommodate the addition of center islands at the intersection. Appropriate lane striping was applied to the road prior to the islands. In the Before Condition there was a stop sign on the right of the approach lane. In the After Condition there was an extra stop sign, also with a “cross traffic does not stop” underbar, on each island. In addition, the mounting poles for the two stop signs that were visible on the approaches from the East and West were changed from white to a reflective red. Figure 2.5 shows the intersection in the After Condition from the East.



Figure 2.5. After Condition—the Simulated Intersection Viewed from the East (Facing West) on CR-9

2.4.4 Change in Vegetation from the Before to the After condition—In the real world, there is vegetation near the T-junction on the approach from the North. To the viewer situated on the East side of CR-9, the combined perceptual effect of this vegetation and the oblique angle of the intersection on the Northeast corner of the intersection, tends to make the traffic North of the vegetation look as if it is not on TH-58. This is illustrated in Figure 2.6—any traffic to the East of the vegetation looks as if it is not on TH-58, although it actually is on it.



Figure 2.6. Simulated Before Condition, with the Vegetation on the Eastside of the Approach from the North (Viewed from the South) Circled in Red

This vegetation present in the Before Condition, was removed for the After Condition. The result is shown in Figure 2.7.



Figure 2.7. Simulated After Condition, with the Vegetation on the Eastside of the Approach from the North (Viewed from the South) Removed from the Area Circled in Red

2.5 Procedure

2.5.1 Consent Form—At the start of each experimental session each participant read and signed a consent form.

2.5.2 Practice Drive—To familiarize each participant with driving in the simulator, he or she was presented with a short training drive. The experimenter sat in the passenger seat of the simulator vehicle during this drive. The participant was instructed to drive at 55 mph while performing a series of lane-changing maneuvers. After performing some lane changes, the participant arrived at a stop sign, and was asked to stop. The experimenter gauged the participant's ability to accurately stop at the stop sign. If the participant needed more practice, the experimenter instructed him or her to drive further down the road and perform a three-point turn. The participant then approached the same stop-controlled intersection from the opposite direction and again attempted to stop at the sign. This procedure was repeated until the experimenter was satisfied that the participant was effectively stopping at the stop sign. The participant was asked if he or she wanted more practice, and was allowed to continue if he or she so desired. At the end of the practice drive, the participant stopped the car, and was given additional information about the experimental session. The experimenter then exited the car and prepared the simulator for the first experimental drive.

2.5.3 Experimental Drives—The participant was informed that he or she would be driving on a two-lane undivided highway with a speed limit of 55 mph, and was asked to drive as he or she “normally would” on an actual highway. The experimenter then asked the participant if he or she had any questions. After answering any questions the participant had, the experimenter presented one of the experimental scenarios, reminded the participant of the speed limit, and asked him or her to drive. The participant drove in four experimental trials. In a single trial, the participant drove the entire length of one of the intersecting roads, starting from North, East, South, or West of the intersection. At the end of each drive, the participant was instructed to turn off the engine and stop the car. The experimenter then prepared for the next drive, and presented it when ready.

2.5.4 Debriefing—After completing all four experimental drives, the participant left the simulator vehicle. Then he or she completed a short questionnaire about the experience of driving in the simulator. In the questionnaire the participant was asked to rate how often he or she drove faster than the posted speed limit. The participant was then debriefed and paid.

Chapter 3 Results

3.1 Increasing the Saliency of the Intersection

A number of changes were made at, and around, the intersection of TH-58 and CR-9 in Goodhue County in an attempt to increase the saliency of the intersection tested in the simulation experiment. Some of these changes were intended to make the intersection more salient for drivers approaching the intersection on the minor road, CR-9. Other changes were made to increase the saliency of the intersection for the drivers approaching on TH-58, the major through road. The effect of these changes on the driving behavior of the participants as they approached the intersection is described in this chapter of the report.

3.2 The Effect of Interventions on Driving Behavior when Approaching the Intersection on the Minor Road (CR-9)

As mentioned in the introduction, increasing the saliency of the intersection could affect the behavior of drivers approaching the intersection from the East and West on CR-9, the minor road, in the following three ways.

- First, the driver may reduce speed earlier, since the intersection should be visible from further away and, as a result, allow the driver to execute a more controlled stop.
- Second, it is less likely that a driver would ignore the stop sign and run through it.
- Third, increasing the saliency of the intersection may make it easier for a driver to stop at a point where he or she can better see the traffic on the crossing road. From this closer position, the driver may have a better view of the crossing road and this, in turn, may reduce the likelihood of the driver pulling out into the space in front of a vehicle on the cross road that is insufficient to allow safe access to the road.

These possible effects are discussed in the next three subsections.

3.2.1 Distance from Intersection at which Participant Began to Reduce Speed—The distance from the intersection at which the participant began to reduce speed was determined by finding the point before the intersection at which each participant took his or her foot off the accelerator. The mean distances from the intersection at which this occurred for the approaches from the East and West for both the Before and After Conditions is presented in Table 3.1.

Table 3.1. Mean Distance from Intersection on the Approaches from the East and West at Which Participant Begins to Reduce Speed

Condition	Approach from East	Approach from West
Before (n = 24)	237.2 meters (778.2 ft)	236.6 meters (776.2 ft)
After (n = 25)	263.2 meters (863.5 ft)	301.4 meters (988.8 ft)

When t-tests were conducted on these data, the difference between the Before Condition and the After Condition was not statistically significant for the approach from the East. However, it was significantly different for the approach from the West (with $p = 0.0357$)

3.2.2 Running the Stop Sign—Increasing the saliency of the intersection more should make it less likely that a driver would simply run through the stop sign. However, running a stop sign is a comparatively rare event. Not surprisingly, there were no instances of this behavior in either the Before Condition or the After Condition.

3.2.3 Improving the Sight Lines—This effect was not directly tested, but the finding that drivers in the After Condition began to reduce their speed at a greater distance from the intersection than the drivers in the Before Condition would seem to indicate that (in the After Condition) the intersection was more noticeable to the drivers. Because the intersection was more noticeable it may have been easier for a driver to stop at a point where he or she could better see the traffic on the crossing road. From this closer position, the driver may have had a better view of the crossing road and this, in turn, may have reduced the likelihood of the driver pulling out into the space in front of a vehicle on the crossing road that was insufficient to allow safe access to the road.

3.3 The Effect of Interventions on Driving Behavior when Approaching the Intersection on the Major Road (TH-58)

To determine whether the interventions implemented for the After Condition were effective in changing the behavior of the participants when they were traveling on TH-58, we compared the speeds at which the participants approached the intersection in the Before Condition and the After Condition. In order to examine the average speed of the participants, we segmented the last 2,000 meters (6560 ft) before the intersection into increasingly finer segments. There were 11 segments as follows—

- From 2,000 meters (6560 ft) to 500 meters (1640 ft) out from the intersection, we segmented the road into three 500-meter (1640-ft) segments.
- Then, from 500 meters (1640 ft) to 100 meters (328 ft) out from the intersection, we segmented the road into four 100-meter (328-ft) segments.
- And finally, from 100 meters (328 ft) to the intersection, we segmented the road into four 25-meter (82-ft) segments.

The speeds at which the participants drove in these 11 segments in the Before Condition and the After Condition were determined on the approaches to the intersection from both the North and South. The analyses of the speed data for the two approaches are described in the next two subsections.

3.3.1 Approach from North of the Intersection— When the speed data for the 11 road segments on the approach from the North were inspected, the participants in the After Condition appeared to fall into two groups. The first group consisted of 20 participants whose speed did not vary much as they approached the intersection, while the second group consisted of five participants who greatly reduced speed as they approached the intersection. For purposes of analysis, these two groups were treated separately—as an After Group and a Slow After Group, respectively.

Then an Analysis of Variance (ANOVA) was conducted on the segmented speed data obtained on the approach from the North. It compared the speed at which the participants in the Before Condition (n = 24), the After Group (n = 20) and the Slow After Group (n = 5) drove as they approached the intersection. The summary of this ANOVA is shown in Table 3.2.

Table 3.2. Summary of the Two-Way ANOVA Comparing the Speeds Driven in the Before Condition, the After Group and the Slow After Group, for the 11 Road Segments on the Approach from the North on TH-58

Source of Variation	Degrees of Freedom	Sum of Squares	Mean square	F-value	P-Value
Between Conditions	2	39,442.149	19,721.075	15.708	<0.0001
Error Term I—Subjects (Within Groups)	46	57,750.856	1,255.453		
Between Distances	10	25,860.644	2,586.064	32.316	<0.0001
Interaction (Conditions X Distances)	20	11,129.819	556.491	6.954	<0.0001
Error Term II—Distances X Subjects (Within Groups)	460	36,811.541	80.025		

As Table 3.2 indicates, in this ANOVA both main effects and the interaction between them were statistically significant. Tukey-Kramer post-hoc tests were conducted for each of the 11 road segments. These tests showed that the participants in the Slow After Group drove significantly more slowly than the participants in the After Group and the Before Condition in nine of the 11 road segments. There were no significant differences in speed between the participants in the After Group and the Before Condition in any of the road segments

Specifically, the participants in the Slow After Group drove significantly more slowly in the four 25-meter (82-ft) segments that were closest to the intersection, in the four 100-meter (328-ft) segments that were next closest to the intersection, and in the closest of the three 500-meter (1640-ft) segments. The speed at which they drove in the remaining two 500-meter (1640-ft) segments—i.e., when they were between 1000 meters (3280 ft) and 2000 meters (6560 ft) from the intersection—were not significantly different from the speed at which the participants in the After Group and the Before Condition drove. These interaction effects, as well as the two main effects (Between Conditions and Between Segments) are illustrated in Figure 3.1.

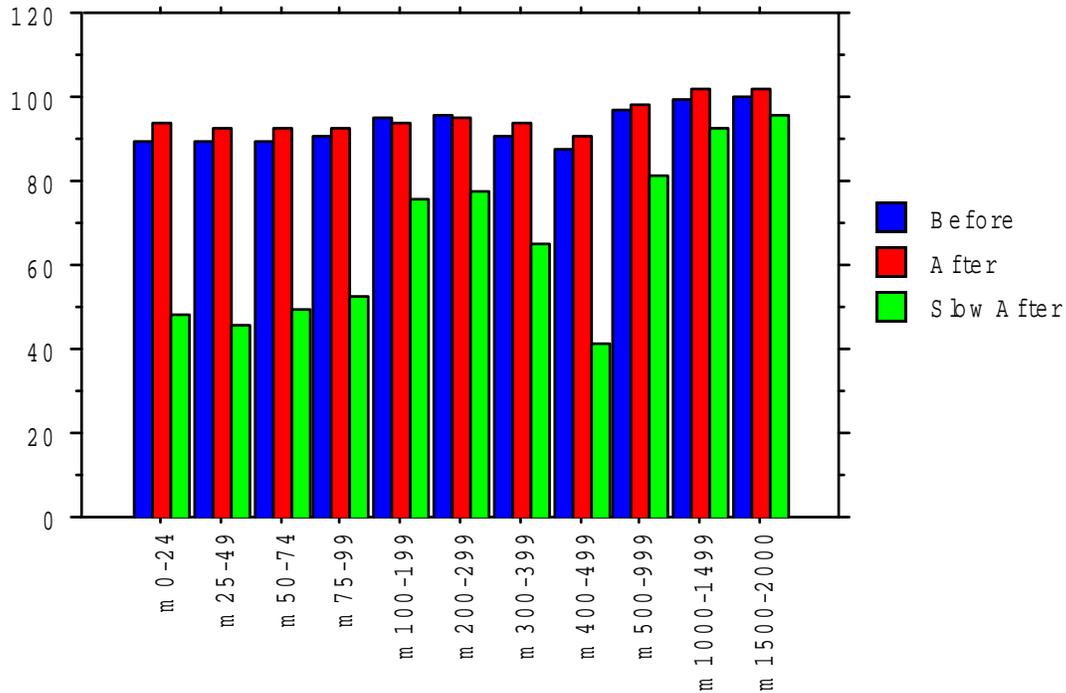


Figure 3.1. Mean Speed (km/h) for the Participants in the Before Condition, the After Group, and the Slow After Group in Each Segment of the Approach from the North on TH-58

Figure 3.1 shows that the Slow After Group began to drive much more slowly (i.e., at less than half the speed of the other participants) when they were between 400 meters (1312 ft) and 500 meters (1640 ft) from the intersection. As mentioned in Chapter 2 of this report, it was approximately 500 meters (1,640 ft) before the intersection on the approach from the North that TH-58 bends to the left while there is a T-junction to the right. It was also at this point—just before the T-junction—that a sign warning of the intersection ahead was added in the After Condition.

Figure 3.1 also shows that during the last 100 meters (328 ft) before reaching the intersection, the participants in the After Group and the Before Condition were driving at approximately 90 km/h (56 mph), while the participants in the Slow After Group were driving a little under 50 km/h (31 mph) (i.e., they were driving 40 km/h (25 mph) slower than the other participants).

3.3.2 Approach from South of the Intersection—When the speed data for the 11 road segments on the approach from the South were inspected, the participants in the After Condition did not fall into two groups (as they did for the approach from the North). Consequently, they were not divided into two groups. The ANOVA conducted on the segmented speed data obtained on the approach from the South compared the speed at which the participants in the Before Condition (n = 24), and the After Condition (n = 25) drove as they approached the intersection. The summary of this ANOVA is shown in Table 3.3.

Table 3.3. Summary of the Two-Way ANOVA Comparing the Speeds Driven in the Before Condition and the After Condition, for 11 Road Segments of the Approach from the South on TH-58

Source of Variation	Degrees of Freedom	Sum of Squares	Mean square	F-value	P-Value
Between Conditions	1	7,275.973	7,275.973	5.560	0.0226
Error Term I—Subjects (Within Groups)	47	61,509.028	1308.703		
Between Distances	10	7,067.468	706.747	13.428	<0.0001
Interaction (Conditions X Distances)	10	1,523.960	152.396	2.895	0.0016
Error Term II—Distances X Subjects (Within Groups)	470	24,737.117	52.632		

Table 3.3 indicates that both main effects and the interaction between them were statistically significant. Tukey-Kramer post-hoc tests were conducted for each of the 11 road segments. These tests showed that the participants in the After Condition drove significantly more slowly than the participants in the Before Condition in eight of the segments. They drove more slowly in the four 25-meter (82-ft) segments that were closest to the intersection, as well as in the four 100-meter (328-ft) segments that were next closest to the intersection. The speed at which they drove at in the three 500-meter (1640-ft) segments—i.e., when they were between 500 meters (1640 ft) and 2000 meters (6560 ft) from the intersection—were not significantly different from the speed at which the participants in the Before Condition drove. These interaction effects, as well as the two main effects (Between Conditions and Between Segments) are illustrated in Figure 3.2.

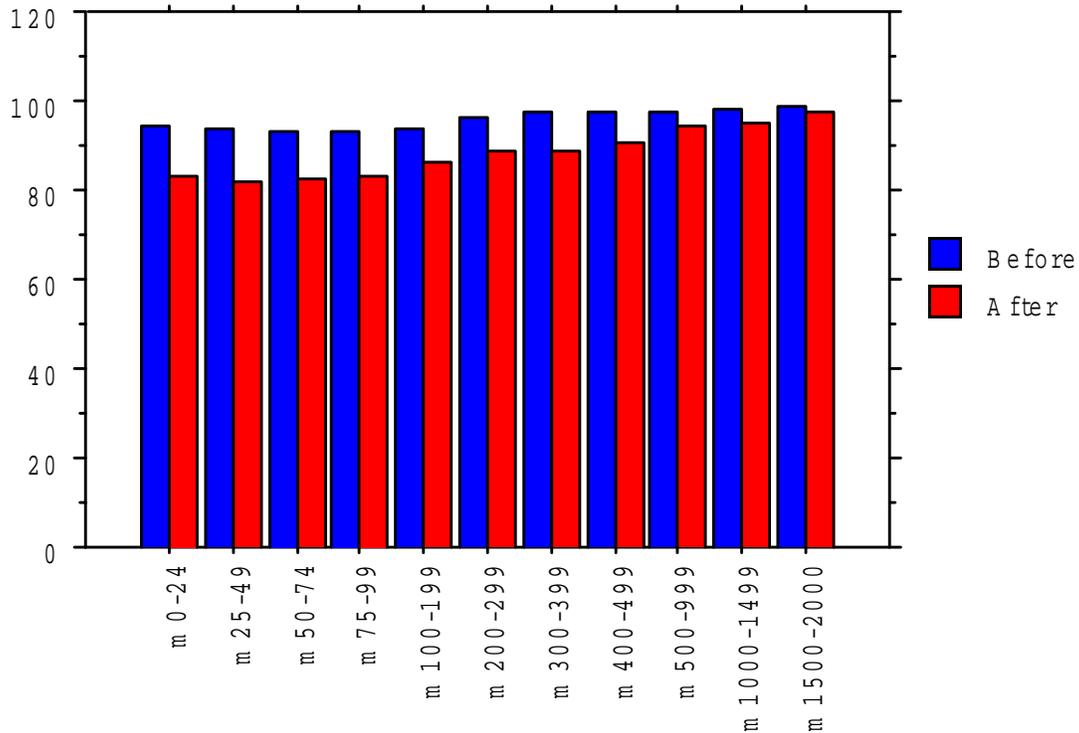


Figure 3.2. Mean Speed (km/h) for the Participants in the Before Condition and the After Condition in Each Segment of the Approach from the South on TH-58

Figure 3.2 shows that the participants in the After Condition were driving 7.6 km/h (4.7 mph) slower than the participants in the Before Condition when they were between 100 meters (328 ft) and 500 meters (1649 ft) from the intersection. The actual mean speeds were 96.4 km/h (59.9 mph) (i.e., above the speed limit) for the Before Condition and 88.8 km/h (55.2 mph) (i.e., at the speed limit) for the After Condition. The figure also shows that the difference in speed increased further—to approximately 11 km/h (6.9 mph) during the last 100 meters (328 ft) before reaching the intersection. For these last 100 meters (328 ft), the actual mean speeds were 93.7 km/h (58.3 mph) (i.e., still above the speed limit) for the Before Condition and 82.7 km/h (51.4 mph) (i.e., below the speed limit) for the After Condition.

Chapter 4 Discussion

4.1 Increasing the Saliency of the Intersection

The objective of the driving simulation experiment that was conducted as part of an investigation of rural Thru-STOP intersections was as follows.

- To determine how a number of interventions, intended to increase the saliency of a particular intersection, affected the behavior of drivers on the major and minor approaches to the intersection.

The interventions were made at, and around, the simulated intersection of TH-58 and CR-9 in Goodhue County. The interventions were as follows—

- Adding traffic islands on CR-9.
- Using two stop signs instead of one on each of the approaches (from the East and West) on CR-9.
- Using reflective posts for the stop signs on CR-9.
- Improving the sight lines for drivers stopped on the East side of CR-9 and looking at the traffic approaching the intersection from the North on TH-58, by removing foliage on the Northeast side of the intersection.
- Adding innovative signage to make the intersection more salient to drivers on TH-58.
- Providing earlier warnings of the intersection to drivers on TH-58.

The first four of these six interventions were intended to make the intersection more salient for drivers approaching the intersection on the minor road, CR-9; the last two interventions were intended to make the intersection more salient for drivers approaching the intersection on the major road, TH-58

4.2 The Effect on Driving Behavior when Approaching the Intersection on the Minor Road (CR-9)

4.2.1 Distance from Intersection at which Participant Began to Reduce Speed—The t-test conducted to compare the distance from the intersection at which the participant began to reduce speed in the Before Condition and the After Condition was also significantly different for the approach from the West (with $p = 0.0357$). This distance increased from 236.6 meters (776.2 ft) to 301.4 meters (988.8 ft).

The distance at which the participant began to reduce speed also increased on the approach from the East, but the increase was smaller than that on the approach from the West and was not statistically significant.

4.2.2 Running the Stop Sign—Although, increasing the saliency of the intersection should make it less likely that a driver would run the stop sign, this behavior occurs relatively infrequently. Because of this, it is not surprising that there were no instances of this behavior in either the Before Condition or the After Condition.

4.2.4 Implications of Interventions for Drivers on the Minor Road—The practical implications of these results are as follows. First, if the driver reduces speed further away from the intersection, he or she should be able to execute a more controlled stop—making it less likely that he or she would inadvertently run the stop sign. If the interventions investigated in this experiment were implemented on real roads they should make the intersection more salient for the drivers on the minor road. In turn this should reduce the likelihood that a driver on the minor road would be involved in a crash.

Also, though the effect of increasing the sight-lines at the intersection was not directly tested, the finding that drivers in the After Condition began to reduce their speed at a greater distance from the intersection than the drivers in the Before Condition seems to indicate that (in the After Condition) the intersection was more noticeable to the drivers. If intersections were more noticeable, it would likely be easier for drivers to stop at a point where they could better see the traffic on the crossing road. From this closer position, drivers may have a better view of the crossing road and this, in turn, might reduce the likelihood of drivers pulling out into the space in front of a vehicle on the crossing road that is insufficient to allow safe access to the road.

4.3 The Effect on Driving Behavior when Approaching the Intersection on the Major Road (TH-58)

In order to determine whether the interventions implemented for the After Condition had an effect on the speed at which the participants drove when they were approaching the intersection on the major road, TH-58, we segmented the last 2,000 meters (6560 ft) before the intersection into increasingly finer segments.

4.3.1 Approach from the North on TH-58—After inspecting the speeds at which the participants in the After Condition drove on the approach from the North, we divided them into two groups. First, there was a group of 20 participants whose speed did not vary much on the approach (the After Group). Second, there was a group of five participants who greatly reduced their speed on the approach (the Slow After Group). An ANOVA conducted on the speed data for the approach from the North indicated that both main effects and the interaction between them were statistically significant. Post-hoc tests showed that the participants in the Slow After Group drove significantly more slowly than the participants in the After Group and the Before Condition, when they were close to the intersection. There were no significant differences in speed between the participants in the After Group and the Before Condition in any of the road segments

The participants in the Slow After Group began to drive at less than half the speed of the other participants when they were between 400 meters (1312 ft) and 500 meters (1640 ft) from the intersection. And, it was approximately 500 meters (1,640 ft) before the intersection on the approach from the North that TH-58 bends to the left and that there is a T-junction to the right.

During the last 100 meters (328 ft) before reaching the intersection, the participants in the After Group and the Before Condition were driving at approximately 90 km/h (56 mph), while the participants in the Slow After Group were driving a little under 50 km/h (31 mph).

This result has important implications for situations in which a vehicle might move from the minor road into the intersection into the path of vehicle traveling on the major road. Because a reduction of 40 km/h (25 mph) would have a very large effect on stopping distance in an emergency, it is much more likely that a right-angle crash would be avoided. Given the relatively low traffic volume on TH-58, reductions in speed are not likely to result in rear-end crashes.

The stopping distance in emergencies can be affected by many different factors including: the type of vehicle involved (automobile, truck, etc), the reaction time of the driver, the condition of the brakes, the tire pressure, the condition of the road surface, etc.

However, MacInnes gives a generally acceptable method for estimating the stopping distances for automobiles traveling on a dry surface with brakes that are in good condition (2). Using MacInnes' method, and assuming the driver has a reaction time of 1 second, the stopping distance for an automobile traveling at 90 km/h (56 mph) will be 67.5 meters (221 ft). In contrast, the stopping distance for an automobile traveling 40 km/h (25 mph) slower (at 50 km/h (31 mph), will be 40.5 meters (132.5 ft) shorter—at 27.0 meters (88.5 ft). So, a 44% (40/90) reduction in speed would result in a 60% (40.5/67) reduction in stopping distance. [Please note, there are more and less conservative methods of estimating stopping distance than that used by MacInnes. They would suggest smaller or larger actual reductions in the stopping distance. However, they would result in similar percentage reductions.]

Reductions in speed of the magnitude that occurred with the participants in the Slow After Group would make crashes far less likely to occur if a driver from the minor road were to move into the intersection. And if there were a crash, it is likely that it would be far less severe.

Another point should be made about the approach from the North and the fact that, while 20% of the participants in the After Condition greatly reduced their speed, the remaining 80% did not. For this remaining 80% of the participants, it may be that the forward view that they saw when they were 500 meters (1,640 ft) before the intersection was too cluttered—with the bend to the left and the a T-junction to the right—so that they focused on the road where the bend and T-junction occurred. As a result, they may not have noticed either the added warning sign (that was presented just before the T-junction) or the innovative signage that was intended to make the intersection more salient to drivers on TH-58—and, therefore, did not reduce speed. It is possible that if a reduced speed limit sign were placed at an appropriate distance ahead of the T-junction, the sign, combined with the interventions tested here, would prompt more drivers to reduce speed before arriving at the intersection.

4.3.2 Approach from the South—When the speed data for the approach from the South were inspected, the participants in the After Condition did not fall into two groups (as they had for the approach from the North). The ANOVA conducted on the speed data obtained on the approach from the South indicated that both main effects and the interaction between them were statistically significant. Post-hoc tests showed that the participants in the After Condition drove significantly more slowly than those in the Before Condition as they approached the intersection. When they were between 100 meters (328 ft) and 500 meters (1649 ft) from the intersection, the

participants in the After Condition drove approximately 7 km/h (4.3 mph) more slowly than the participants in the Before Condition. During the last 100 meters (328 ft), before reaching the intersection, the speed reduction increased—while participants in the Before Condition were driving at approximately 93.5 km/h (58.1 mph), the participants in the After Condition were driving at approximately 82.5 km/h (51.3 mph).

We used MacInnes' estimation method to determine the likely reduction in stopping distance for this difference of 11 km/h (6.8 mph). We used the same assumptions that were used in estimating stopping distances for the approach from the North (i.e., an automobile with brakes that are in good condition, a dry road surface, and a driver reaction time of 1 second). The stopping distance for an automobile traveling at 93.5 km/h (58.1 mph) will be 71.8 meters (236 ft). In contrast, the stopping distance for an automobile traveling at 82.5 km/h (51.3 mph) will be 13.2 meters (44 ft) shorter—at 58.6 meters (192 ft).

In this case, the 11.8% (11/93.5) reduction in speed obtained with the participants in the After Condition results in an 18.4% (13.2/71.8) reduction in stopping distance. Although this reduction is smaller than that obtained for the approach from the North, it would still make crashes less likely and/or less severe if a driver from the minor road were to move into the intersection.

4.3.3 Summary of Effects for Drivers on the Major Road (TH-58)—The interventions implemented in this simulation experiment resulted in 20% of the participants (those in the Slow After Group) who approached the intersection from the North to:

- Reduce their speed by 44% (40/90). This reduction in speed would result in a 60% (40.5/67) reduction in stopping distance.

Also, the interventions implemented in this simulation experiment resulted in the participants in the After Condition who approached the intersection from the North to:

- Reduce their speed by 11.8% (11/93.5). And this reduction would result in an 18.4% (13.2/71.8) reduction in stopping distance.

4.4 Possible Effects of Increasing the Saliency of the Intersection on the Driver's Reaction Time

There is another way in which the apparent increases in the saliency of the intersection could be beneficial. In the examples MacInnes uses to illustrate the method for estimating stopping distances, he assumes the driver will have a reaction time of 1 second (2). In this study we used a 1 second reaction time to estimate the stopping distances for both the Before and After Conditions. However, there is evidence from an experiment recently conducted by Groeger and Hammond (reported in 3), that suggests that the participants in the After Condition in our experiment might have still shorter stopping distances than those estimated above. Using 400 subjects, Groeger and Hammond found that when a subject is alerted to the fact that a response will be required immanently, the speed with which he or she responds by moving his or her foot from a resting position to a foot pedal was likely to be between 450 and 550 ms (3).

It is possible that the interventions we made in order to make the intersection of TH-58 and CR-9 more salient had an alerting effect on the participants in the simulation experiment. If it did have

an alerting effect, instead of assuming the reaction time was 1 second (as we did in our estimation), then it may have been more appropriate to assume a reaction time of 0.5 seconds. Then the reduction in the stopping distances would increase from 60% to 71% (47.5/67) for the Slow After Group on the approach from the North; while the reduction in the stopping distances would increase from 18.4% to 34.4% (24.7/71.8) for the After Condition on the approach from the South.

4.5 ITS Interventions

It should be noted that this project did not address possible Intelligent Transportation Systems (ITS) solutions, although recent developments in the ITS area are promising. One such possible solution (which should be tested either with a driving simulator experiment or in a field test) is the following: a detector could be installed on the major road. It would detect a vehicle approaching the intersection on the major road. It would then be possible to provide a warning to a vehicle on the minor road. The warning would be provided on an active message sign at the roadside.

4.6 Conclusion, Recommendations, and Future Work

The emphasis of this project was on a preliminary investigation of mitigating strategies intended to reduce crashes at controlled rural intersections. A Human Factors analysis of a problem intersection was conducted. The intersection had sight-lines problems. These were addressed with interventions to the infrastructure that were tested in a driving simulation experiment. This driving simulation experiment explored the effect on driving behavior of implementing several interventions aimed at increasing the saliency of a rural intersection in Goodhue County, Minnesota. The results of the experiment revealed that:

- After the intervention, on the minor road the participants began to reduce speed further away from the intersection.
- After the intervention on the major road, 20% of the participants in the After Condition (those in the Slow After Group) reduced their speed by an average of 44% on the approach from the North. All participants in the After Condition reduced their speed by an average of 11.8% on the approach from the South. For both approaches, the reductions in speed would be likely to translate into considerable reductions in stopping distance in the event that a vehicle pulled into the intersection from the minor road and required an emergency stop from the driver on the major road. Given the relatively low traffic volume on TH-58, reductions in speed are not likely to result in rear-end crashes.

These results suggest that the interventions tested in the simulation experiment are promising and would be worth investigating in a field test. The interventions investigated in this project would likely be useful at other rural controlled intersections with sight-limited intersections, particularly those at which the minor road is more important than the gravel roads encountered at previous intersections.

However, unlike the intersection of TH-58 and CR-9, not all rural intersections with similar problems have the light posts required for hanging the signage on the major road. Further analysis should be conducted at other rural controlled intersections to determine other

interventions that might be appropriate at them. There will likely not be a single optimal solution that will fit all problem rural controlled intersections.

Future work could involve categorizing rural intersections with regard to:

- the horizontal cross-angles of the intersection
- vertical curves
- relative position of vegetation and buildings
- relative position of commercial and highway signage
- presence of lighting

Following the categorization process, possible mitigating strategies to modify the infrastructure would be developed.

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Appendix A

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INTRODUCTION/PROBLEM STATEMENT

County engineers around the State of Minnesota identified the frequency and severity of right angle crashes at rural Thru-STOP controlled intersections as being a significant concern. They also suggested that it was commonly believed that the key contributing factor to these crashes were vehicles on the minor road approaches running through the STOP signs.

An informal survey of practice of county highway departments found that the typical approach to designing the traffic control at these rural intersections started with installing a 30 by 30 inch STOP sign. Then, if there were ever an intersection recognition or crash problem the county highway staff would consider a variety of alternatives contained in their traffic safety tool box; including:

- adding rumble strips or overhead flashers
- adding a supplemental plaque to the STOP sign (CROSS TRAFFIC DOES NOT STOP)
- adding either bigger or additional STOP signs

However, a series of research reports has suggested that these strategies have not been consistently effective at reducing crashes. Research conducted by Iowa State University (Ref. 1) analyzed more than one-hundred locations in Iowa and concluded that intersections with rumble strips had a higher crash frequency than comparable intersections without rumble strips. A similar study of twenty-five intersections in Minnesota came to the same conclusion (Ref. 2). A study by the University of Minnesota of red/yellow overhead flashers installed at rural Thru-STOP controlled intersections found that they not only didn't reduce crashes, but in a driving simulator environment they also appeared to confuse drivers into thinking that the intersection was actually controlled by an All-Way STOP (Ref. 3). (Following the release of this study, MnDOT issued a technical memo to their District's requesting the removal of these devices.) The University of Arkansas found the CROSS TRAFFIC DOES NOT STOP plaque to be of limited effectiveness because of inconsistent usage of the plaque and the fact that most drivers do not understand the concept of just exactly what is cross traffic (Ref. 4). And finally, prior to the current study conducted by Harder, Bloomfield and Chihak using the University of Minnesota's driving simulator there was virtually no research documenting the effectiveness of either larger or additional STOP signs. There is one additional key point, the basic approach used by the typical county engineer to address rural intersection safety appears to assume that the primary contributing factor is lack of recognition of the STOP sign by drivers on the minor road approaches (which results in the vehicles on the minor road running through the STOP signs). However, there is nothing in the literature to suggest that this is a valid assumption.

Therefore, the Minnesota Local Road Research Board adopted as an objective - the identification of new mitigation strategies for inclusion in the County Engineer's Safety Tool Box, based on addressing the root causes of rural intersection crashes.

APPROACH

The basic approach to addressing the traffic engineering issues associated with safety at rural intersections consisted of the following four key steps:

1. Describing the basic geometric characteristics of typical rural Thru-STOP intersections and then using MnDOT's crash records data base to identify the actual crash profile (crash frequency, severity, type, etc.) for a set of similar intersections and then identifying high frequency intersections.
2. Reviewing the actual police crash reports of a sample of the total crashes (i.e., all right angle crashes) in order to document the cause of the crash as noted by the investigating officer.
3. Randomly selecting a sample of the high crash frequency intersections, conducting a field review at the selected locations and documenting the basic roadway geometry and intersection area traffic control devices.
4. Identifying potential mitigation strategies that are directly linked to the documented crash causes and contributing factors.

Crash Analysis Results

The crash data analysis began by describing the geometric characteristics of the typical rural intersection in order to screen out those intersections with features that could result in baseline crash patterns that are not representative of the desired conditions. Conversations with a number of county engineers indicated that the typical features of their rural intersections include:

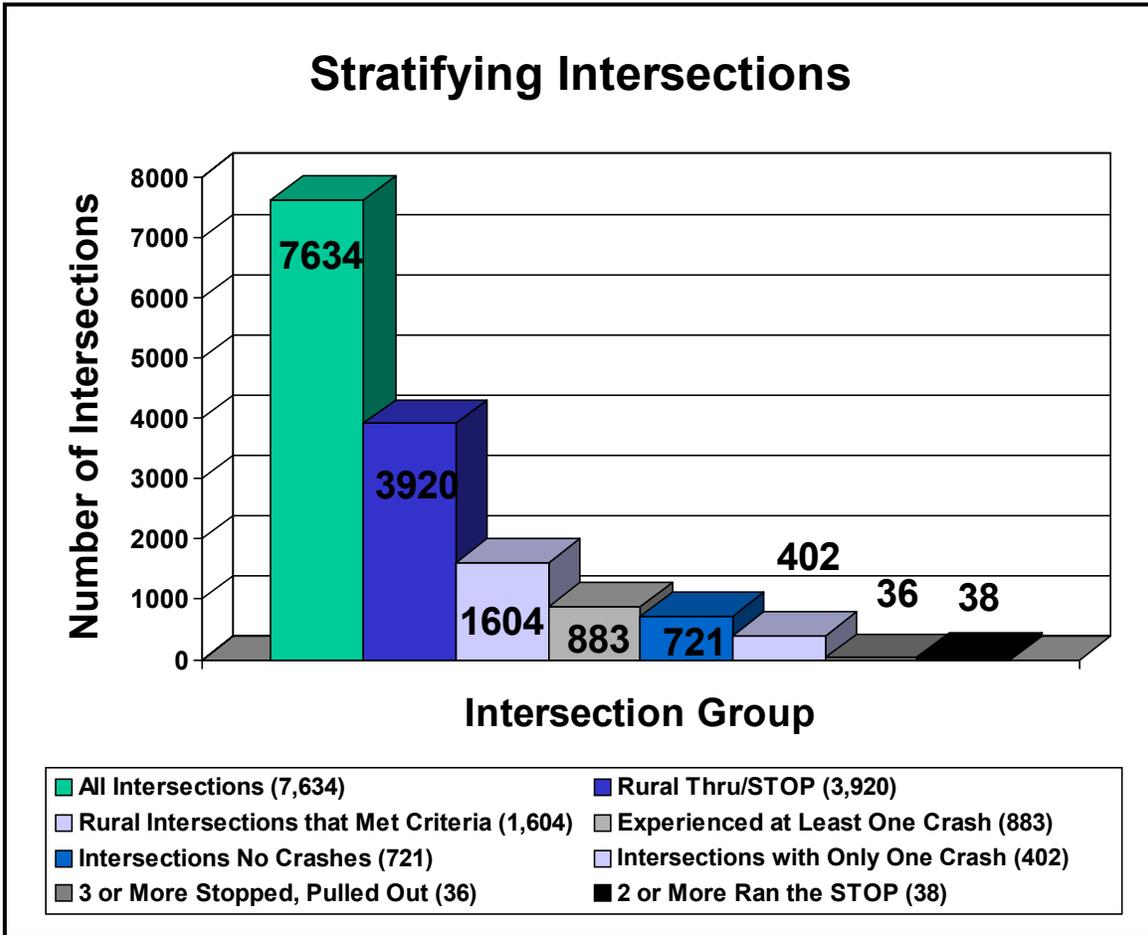
- 2-lane roadways only
- No medians or auxiliary turn lanes
- Four legs of approach
- Thru-STOP intersection control

The search of MnDOT's transportation information database found a total of 7,634 intersections along the State's system of trunk highways, of which 3,920 (51%) were classified as Rural and Through/STOP and 1,604 (21%) were found to meet all of the search criteria (see **Figure 1**). It should be noted that the study was limited to state highway intersections with county highways, county roads and other local roads (primarily township roads) because of the need to access MnDOT's roadway information data. Similar roadway and traffic control databases do not currently exist for county and local roads.

MnDOT's crash records database was then used to document the crash characteristics for the group of 1,604 similar intersections and for each intersection in the group over an almost three year study period. The key results of this analysis include the following:

- 721 (45%) intersections had no crashes.
- 883 (55%) intersections had at least one crash.

- There were a total of 2,296 crashes at the 1,604 intersections.
- Right angle crashes were the most common type of intersection crash (768 crashes/33%) and the most severe (62% of serious injuries and 71% of fatalities).
- This group of intersections averaged 0.6 crashes per intersection per year and



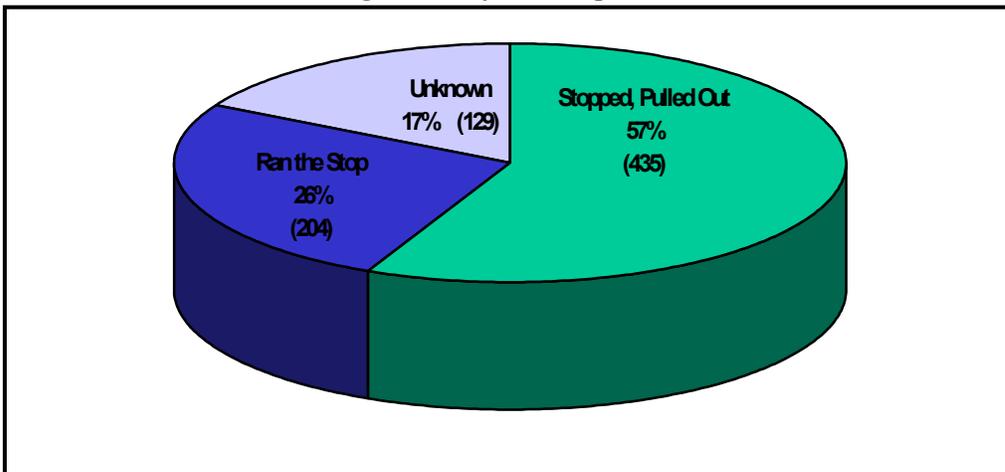
approximately 0.2 right angle crashes per intersection per year.

Figure 1: Intersection Stratification

The results of the review of MnDOT’s crash records database confirms the county engineers concerns about right angle crashes at typical rural, Thru-STOP intersections. Right angle crashes are the most frequent type of crash at these intersections and the most severe. However, the crash records database could not provide detailed information relative to either the causes of the crashes or any background information about the drivers involved in these crashes.

As a result of the limitations of the crash records database, the actual police crash reports for the 768 right angle crashes were reviewed. These reports revealed the following information:

- 435 right angle crashes (57%) involved a vehicle that had stopped at the STOP sign and then Pulled Out (see **Figure 2**).
- 204 right angle crashes (26%) involved a vehicle that Ran Thru the STOP sign (see **Figure 2**).
- 129 right angle crashes (17%) could not be identified relative to vehicle actions (either vehicle action prior to the crash wasn't documented or there was conflicting information – **Figure 2**).
- Right angle crashes caused by vehicles Running Thru the STOP sign are more severe than STOP and Pull Out crashes (and much more severe than the average for all crashes in Minnesota over the same time period – **Figure 3**).
- A total of 156 intersections (10%) had Ran Thru the STOP crashes, of which 118 (7%) had only one crash and only 38 (2%) had two or more crashes during the study period. Only 1% of these intersections averaged more than one Ran Thru the STOP crash per year.
- A total of 251 intersections (16%) had STOP and Pull Out crashes, of which 162 (10%) had only one crash and only 36 (2%) had three or more STOP and Pull Out crashes during the study period. Only 10% of these intersections averaged more than one STOP and Pull Out crash per year.
- Most of the right angle crashes occurred during daylight conditions. However, the percentage of Ran Thru the STOP crashes that occurred after dark (18%) is approximately twice the rate for both STOP and Pull Out (8%) crashes and the rate for all crashes in Minnesota (10%).
- The age of drivers involved in both Ran Thru the STOP and Stop and Pull Out crashes was compared to the expected distribution based on Statewide crash totals (see **Figure 4**). The data indicates that drivers between the ages of 25 and 40 are significantly over represented in Ran Thru the STOP crashes and



drivers less than 19 and over 85 are over represented in STOP and Pull Out crashes.

Figure 2: Distribution of right Angle Crash Type at Study Intersections

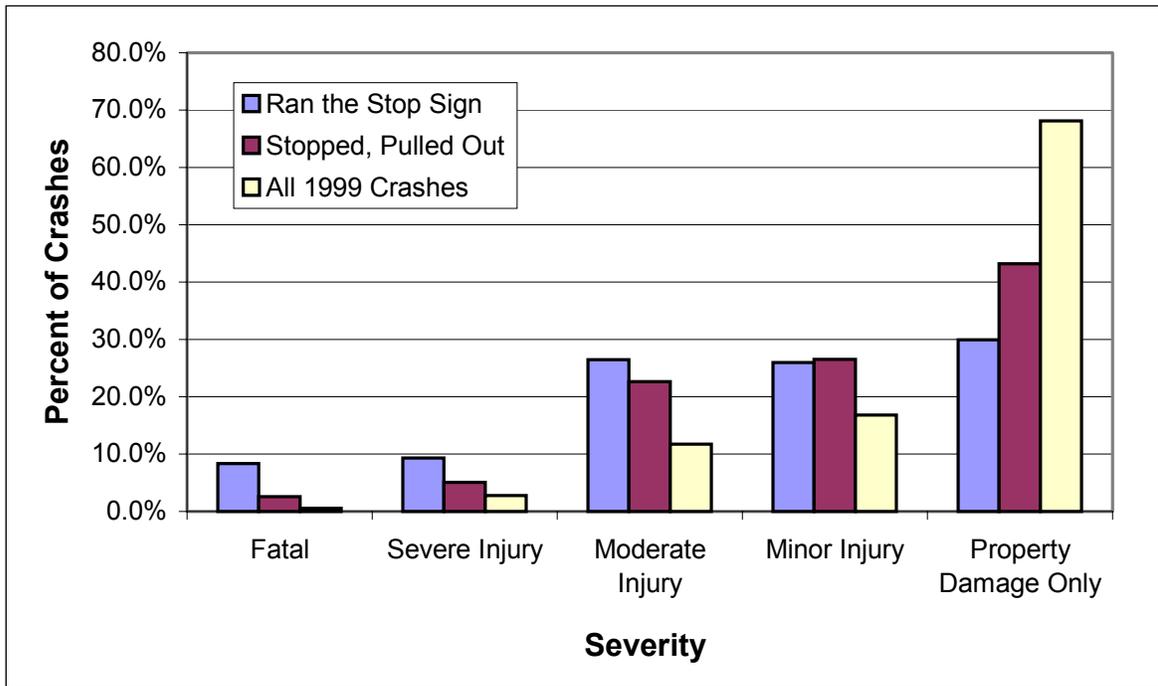


Figure 3: Right Angle Crash Severity

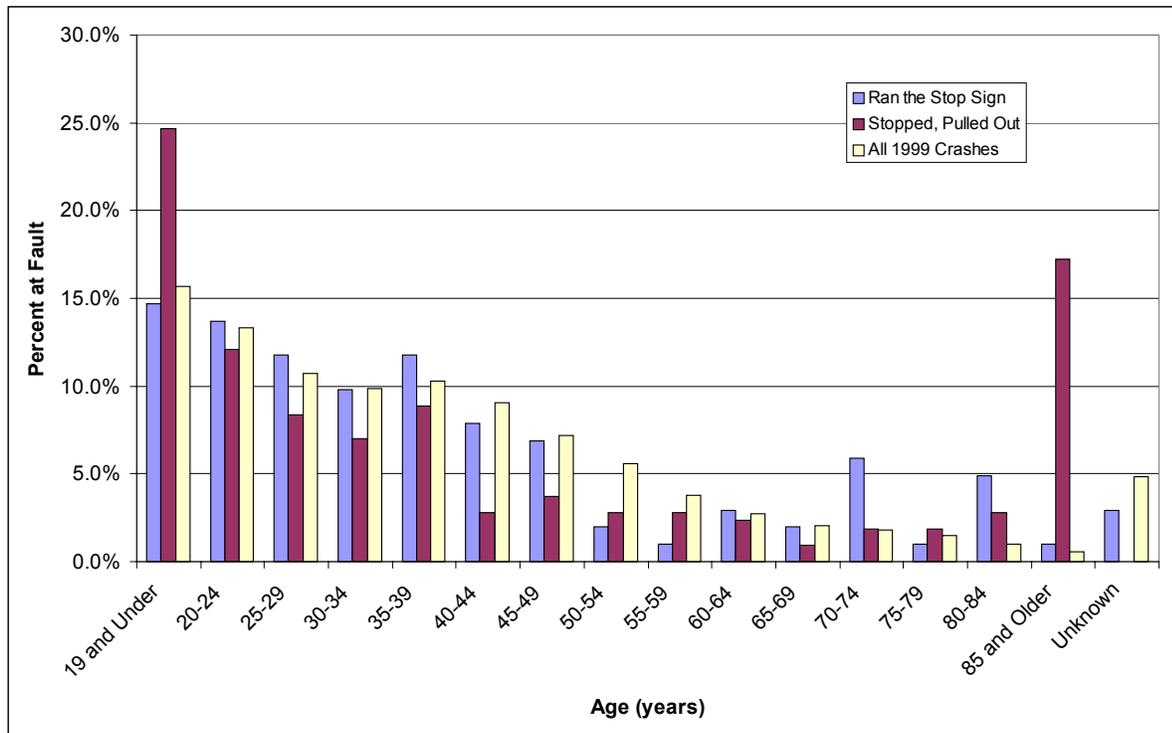


Figure 4: Age Distribution

Field Review of Selected Intersections

The final step in the analytical process involved randomly selecting a sample of ten intersections from each of three different categories for field review. The three categories of intersections identified for review include; intersections with multiple Ran Thru the STOP crashes, intersections with multiple Stop and Pull Out crashes and as a comparison intersections with no crashes during the study period. The objective of this effort was to determine if the basic design and/or traffic control features could be contributing to the higher than expected frequency of right angle crashes. The focus on intersections with multiple crashes was based on the expectation that intersections with only one crash during the study period were most likely examples of the random nature of crashes while intersections with multiple crashes would have a far higher probability of somehow being different than the other intersections in the group and that the difference was contributing to the higher than expected frequency of crashes.

The thirty intersections (10 per category) selected for the field review are identified in **Table 1**, along with the basic crash characteristics and the critical crash rate. The critical crash rate is a statistical quality control technique. Intersection crash rates higher than the critical rate are an indication that the crash frequency is statistically significantly higher than expected and that the difference is most likely due to conditions at the intersection (as opposed to the random nature of crashes). It should be noted that 19 of the 20 intersections selected for review have crash rates equal to or greater than the critical rate. This suggests that the use of multiple crashes as a selection criteria was a valid approach to identifying intersections where something was different.

The field review documented the following features:

- Signs – number, size, placement and condition of STOP and STOP AHEAD signs
- Intersection Sight Distance (from the minor road approaches)
- Sight Obstructions to Signs (along the minor road approaches)
- Presence of Other Devices (street lights, pavement markings, rumble strips)
- Proximity to Other Controlled Intersections (along the minor roads)
- Daily Traffic Volumes

The key observations derived from the field review follow. It should be noted that these observations are merely that - observations, and because of the limited sample size are not statistically significant.

Signs

- At intersections with crashes, the use of more and larger STOP signs appears to reduce the number of Ran the STOP crashes.

Table 1: Field Review Intersections

	Major Street	Minor Street	County	Number of "Stopped, Pulled Out" Crashes	Approach Volume	Total Crashes	Crash Rate	Critical Crash Rate	Severity Rate
Stopped, Pulled Out	USTH 12	CSAH 92	Hennepin	3	12,860	6	0.5	0.7	1
	MNTH 3	160th Street CSAH 46	Dakota	5	8,350	12	1.6	0.7	3.5
	MNTH 3	Rich Valley Blvd	Dakota	4	8,870	8	1.0	0.7	2.5
	MNTH 25	CSAH 37A	Wright	4	13,340	13	1.1	0.7	2.3
	MNTH 23	CSAH 18	Yellow Medicine	3	3,850	5	1.4	0.8	4
	MNTH 25	CR 106 & T225	Wright	3	13,080	9	0.8	0.7	2
	USTH 61	170th Street CSAH 4	Washington	4	10,250	10	1.1	0.7	2.7
	MNTH 7	CSAH 10	Carver	10	9,910	15	1.7	0.7	4.6
	MNTH 60	TH 57	Goodhue	3	4,070	7	1.9	0.8	5.1
MNTH 23	CSAH 12	Kanabec	3	4,810	8	1.8	0.8	4.6	
Number of "Ran the Stop" Crashes									
Ran the Stop	MNTH 246	CSAH 1 and CR 81	Rice	2	3,920	8	2.2	0.8	6.4
	MNTH 57	CSAH 22	Dodge	2	1,540	2	1.4	0.9	3.6
	MNTH 95	CSAH 7 and CR 57	Mille Lacs	2	4,420	6	1.5	0.8	4.5
	MNTH 95	CSAH 7 and CR 57	Isanti	2	5,370	6	1.2	0.8	2.4
	MNTH 200	CSAH 4	Mahnomen	2	1,400	3	2.4	0.9	7.1
	USTH 71	CSAH 4	Renville	2	3,670	3	0.9	0.8	3.6
	USTH 61	190th Street	Washington	2	6,430	7	1.2	0.7	2.7
	USTH 212	CSAH 43	Carver	3	9,790	6	0.7	0.7	2
	MNTH 4	CR 186B	Stearns	2	1,750	6	3.8	0.9	11.3
	MNTH 23	CSAH 12	Kanabec	2	4,810	8	1.8	0.8	4.6
No Crashes	MNTH 104	CSAH 13 LT	Kandiyohi		730	0	0.0	0.9	0
	USTH 8	HAMLET AVE	Chisago		18,200	0	0.0	0.6	0
	MNTH 96	OAK GLEN TR	Washington		5,070	0	0.0	0.8	0
	MNTH 5	CSAH 50	Carver		4,240	0	0.0	0.8	0
	MNTH 50	JOAN AVE	Dakota		4,410	0	0.0	0.8	0
	MNTH 21	230TH ST C	Scott		4,210	0	0.0	0.8	0
	MNTH 210	CSAH 65	Otter Tail		1,340	0	0.0	0.9	0
	MNTH 25	CSAH 47	Morrison		1,740	0	0.0	0.9	0
	MNTH 4	CR 179	Stearns		1,350	0	0.0	0.9	0
	MNTH 30	CSAH 8	Olmsted		3,060	0	0.0	0.8	0

NOTE: Shaded rows indicate intersections with crash rates over the critical rate.

- The placement of STOP signs does not appear to be an issue. There was very little variation in the placement of the signs from intersection to intersection and the placements were all in substantial compliance with the guidelines in the MNMUTCD.
- The use of brighter retroreflective sheeting material appears to reduce the frequency of both total crashes and right angle crashes. The highest usage of diamond grade sheeting was at intersections with no crashes and the lowest usage was at intersections with multiple Ran the STOP crashes.
- STOP AHEAD signs were in place at all but one intersection. At intersections with crashes, it appears that the use of larger, brighter advance warning signs reduces the frequency of Ran Thru the STOP crashes.

Intersection Sight Distance

- Intersection sight distance does not appear to be related to the frequency of STOP and Pull Out crashes.
- Each category had about the same number of intersections (between 2 and 4) with less than adequate intersection sight distance (Assumed to be 10 seconds, consistent with the basic guidance in the AASHTO Green Book – Ref. 5).
- The category with multiple STOP and Pull Out crashes had the fewest number of intersections with less than adequate sight distance.

Sight Obstructions to STOP Signs

- Sight obstructions to STOP signs does not appear to be related to the frequency of Ran the STOP crashes.
- Intersections with no crashes had the lowest frequency of obscured signing (1). However, the intersections with multiple Ran the STOP crashes only had two instances of obscured signing.

Presence of Other Devices

- Intersections with crashes and street lights had a much lower frequency of both night time crashes and Ran the STOP crashes.
- Intersections with STOP AHEAD pavement markings had a lower frequency of Ran the STOP crashes.
- Intersections with rumble strips on the minor road approach had the same frequency of Ran the STOP crashes as intersections without rumble strips.

Proximity to Other Controlled Intersections

- Proximity to other controlled intersections (along the minor road) may be related to total crash frequency. All of the intersections with both multiple STOP and Pull Out and Ran Thru the STOP crashes were more than a mile away from the nearest controlled intersection, while only one-half of the

intersections with no crashes were more than a mile from another controlled intersection.

Daily Traffic Volumes

- The intersections with multiple STOP and Pull Out crashes had the highest traffic volumes, with the average daily approach volume in the range of 9,000 vehicles per day. The other two intersection categories each had average approach volumes in the range of 4,500 vehicles per day.

During a review of this material with the advisory panel of county engineers, it was requested that the crash data for the sample of intersections with multiple crashes be analyzed to determine if unfamiliar motorists were contributing to the frequency of crashes. The analysis consisted of identifying the location of each crash and the home city of each of the “at fault” drivers and then documenting the distance between the two. The results of this analysis indicate that the average distance between home and crash site is less than 10 miles and 80% of the distances are less than 30 miles. This would suggest that unfamiliar drivers do not appear to be over represented in either STOP and Pull Out or Ran Thru the STOP crashes. This might also suggest that, in rural areas with relatively low traffic volumes, drivers who are in fact familiar with the road and know that traffic is fairly infrequent might not be paying sufficient attention.

POTENTIAL MITIGATION STRATEGIES

The results of the analysis of the crash data and the field review of the selected intersections suggest the need to develop two basic approaches to addressing the issue of right angle crashes at rural through/STOP intersections. The first would have to address the most prevalent type of crash, STOP and Pulled Out, where the primary contributing factor is gap selection. The second would then address the Ran the STOP types of crashes, where the primary contributing factor is intersection recognition. The results of the crash analysis also suggests that due to the very low frequency of occurrence of either type of crash (an average of less than .1 crashes per intersection per year), the most effective implementation would most likely involve a systematic approach instead of an approach focused on the very small number of locations with multiple crashes.

It appears that there are two types of strategies for addressing the issue of gap selection, static and dynamic. The Pennsylvania Department of Transportation has experimented with the use of pavement markings to identify unsafe gaps. Other possibilities include the use of sign posts or street light poles to identify the limits of unsafe gaps on the major street approaches to intersections. An example of how these devices could be deployed would consist of placing a series of street lights on the major street approaches, with the last street light at the limits of the unsafe gap - current research (Ref. 5) suggests that a safe gap at a rural intersection would be in the range of 650 to 800 feet (approximately 8 to 10 seconds at a posted 55 mile per hour speed limit). A dynamic system could use either optical detectors or radar to sense the location of vehicles approaching the intersection on the major street and then using some type of changeable message sign to inform the driver waiting at the STOP sign on the minor street. The University of Minnesota has just begun a research project that

will look at developing and evaluating alternative dynamic technologies to assist with the gap selection process.

It appears that there are also static and dynamic strategies for addressing the issue of intersection recognition. The static strategies would increase the conspicuity of traffic control devices by making them larger, brighter or using additional signs and markings. The dynamic approach could use optical detectors or radar to sense the speed of vehicles on the minor street approaches and then use some type of changeable message sign to warn drivers on the major street to take action to avoid vehicles that appear to be going too fast to stop prior to entering the intersection. Virginia Tech has just begun a research project that will look at developing and evaluating alternative dynamic technologies to warn of STOP sign and traffic signal violators.

In either case, a complementary component to developing and deploying new or additional devices would include an educational program for drivers. Drivers would have to be taught what these devices mean and what they would need to do to effectively use the information in order to prevent crashes.

CONCLUSIONS

The review of MnDOT's crash records data base and police crash reports indicates the following:

- Almost one-half of the 1,604 rural Through/STOP intersections in the data base experienced no crashes during the 2+ year study period.
- This group of intersections averaged 0.6 crashes per intersection per year and approximately 0.2 right angle crashes.
- Right angle crashes account for more crashes than any other type.
- Right angle crashes are the most severe type of crash, accounting for nearly 71% of the fatal crashes.
- The most common type of right angle crash (approximately 60%) involves a vehicle Stopping and then Pulling Out into an unsafe gap. Approximately 25% of the right angle crashes involved a minor street vehicle Running through the STOP sign. (The remaining right angle crashes could not be classified.)
- The occurrence of STOP and Pull Out crashes is not wide spread. 251 intersections experienced one of these crashes (out of a total of 1,604 intersections over a 2+ year study period). Only 89 intersections experienced two or more STOP and Pull Out crashes.
- The occurrence of Ran the STOP crashes is not wide spread. 118 intersections experienced one of these crashes and only 38 intersections experienced two or more Ran the STOP crashes.

- Light condition at the intersection appears to be a contributing factor. Vehicles are running the STOP signs at intersections without street lights at twice the statewide average for all crashes.
- The age of the driver appears to be a contributing factor. Drivers under 20 and over 85 are over represented in STOP and Pull Out crashes and drivers between the ages of 25 and 40 are over represented in Ran the STOP crashes.
- Increasing the conspicuity of traffic control devices by using bigger, brighter or additional signs and markings appears to lower the frequency of Ran the STOP crashes.
- Rumble strips do not appear to be effective at reducing the frequency of Ran the STOP crashes (intersections with and without rumble strips had the same frequency of crashes).
- Intersection sight distance does not appear to be related to the frequency of gap selection related crashes.
- Proximity to other controlled intersections may be related to crash frequency.

These conclusion suggest that some of the old strategies in the Intersection Safety Tool Box should be discarded because they have no history of being consistently effective (rumble strips on the approach to intersections, red/yellow overhead flashers and the CROSS TRAFFIC DOES NOT STOP sign). In addition, these conclusions appear to support the development of two new types of mitigation strategies, the first focused on improving the ability of drivers on the minor street to identify safe gaps in traffic approaching on the major road and the second focused on addressing the issue of intersection recognition. These strategies would then be candidates for the Intersection Safety Tool box if and when they are able to demonstrate their effectiveness.

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