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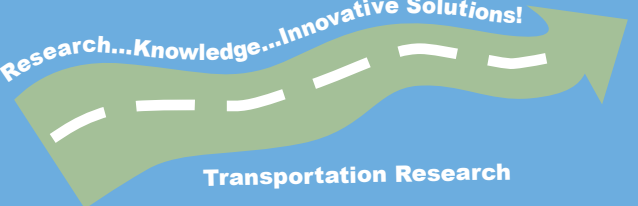Intersection Decision Support: An Overview

Report #6 in the Series: Developing
Intersection Decision Support Solutions

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16. Abstract (Limit: 200 words)

Minnesota joined with California, Virginia, and the FHWA in a pooled fund consortium (the Infrastructure Consortium) dedicated to improving intersection safety. The Minnesota team's objective is to develop effective strategies to mitigate high crash rates at rural intersections.

Rural Intersection Decision Support (IDS) focuses on enhancing the driver's ability to successfully negotiate rural intersections. The system uses sensing and communication technology to identify safe gaps in traffic on a high-speed rural expressway and communicate this information to drivers waiting to enter the intersection from a minor intersecting road. The goal of this system is to improve safety without introducing traffic signals, which on high-speed rural roads often lead to an increase in rear-end crashes.

The Rural IDS research program achieved four main research results: an analysis of rural expressway intersections, including development of a technique to identify those with higher-than-expected crash rates; development of a statistical model that can be used to estimate the benefits of deploying IDS at a specific rural intersection; design and implementation of a rural intersection surveillance and data acquisition system capable of quantifying the behavior of drivers; and a task analysis, design study, and simulator-based evaluation of Driver Infrastructure Interface (DII) concepts for communicating relevant information to stopped drivers.

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Intersection Decision Support:
An Overview

Report #6 in the Series: Developing
Intersection Decision Support Solutions

Final Report

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September 2007

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Executive Summary

In the year 2003, approximately 41% of all vehicle crashes in the US occurred at intersections; these crashes resulted in nearly 9,000 fatalities, or approximately 23% of all traffic fatalities. Of these intersection-related fatal crashes, 68% occurred at unsignalized intersections (no stop signs, controls, or other signs).

In rural Minnesota, approximately one-third of all crashes occur at intersections. From 1998-2000, 62% of all intersection-related *fatal crashes* in Minnesota occurred at rural through/stop intersections. The American Association of State Highway and Transportation Officials (AASHTO) recognized the significance of rural intersection crashes in its Strategic Highway Safety Plan (SHSP), and identified the development and use of new technologies as a key initiative to address the problem of intersection crashes.

In the rural Intersection Decision Support System (IDS) proposed here, infrastructure-based sensing and communication technology is used to determine the safe gaps in traffic and then communicates this information to the driver so that he or she can make an informed decision about entering a major road traffic stream.

In this document, we summarize the results of the rural IDS project. Briefly, these include:

1. An analysis of rural expressway intersection crashes in Minnesota, including the development of a technique to identify intersections having crash rates higher than expected;
2. A statistical model that can be used to estimate or project the societal benefits of deploying a rural stop sign assistant at rural intersections;
3. The design, development, and implementation of a rural intersection surveillance and data acquisition system. (Gap acceptance behavior of drivers at a live intersection has been quantified, and two crashes have been captured.); and
4. A task analysis, design study, and simulator-based evaluation of innovative Driver-Infrastructure Interface (DII) concepts for communicating to the stopped driver, leading to an understanding of the timing and content of information needed for an effective, acceptable DII.

Introduction

In the year 2003 approximately 41% of all vehicle crashes in the US occurred at intersections; these crashes resulted in nearly 9,000 fatalities, or approximately 23% of all traffic fatalities. Of these intersection related fatal crashes, 68% occurred at unsignalized intersections (no stop signs, controls, or other signs) (NHTSA, 2005).

To address the intersection crash problem, the FHWA sponsored Infrastructure Consortium, consisting of state Department of Transportations (DOTs) and Universities from Minnesota, Virginia, and California, created the Intersection Decision Support (IDS) project, which was formed and given the task of developing technologies and approaches to mitigate the intersection crash problem. Three different problems were addressed as part of this initiative. Virginia addressed signalized and stop controlled intersection violations and crashes. California addressed Left Turn Across Path/Opposite Direction (LTAP/OD) violations, primarily in the urban and suburban setting. Minnesota elected to address crashes at rural unsignalized intersections.

In rural Minnesota, approximately one-third of all crashes occur at intersections. From 1998-2000, 62% of all intersection-related *fatal crashes* in Minnesota occurred at rural through/stop intersections. The American Association of State Highway and Transportation Officials (AASHTO) recognized the significance of rural intersection crashes in its Strategic Highway Safety Plan (SHSP), and identified the development and use of new technologies as a key initiative to address the problem of intersection crashes.

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1. An analysis of rural expressway intersection crashes in Minnesota, including the development of a technique to identify intersections having crash rates higher than expected.
2. A statistical model which can be used to estimate or project the societal benefits of deploying a rural stop sign assistant at rural intersections.
3. The design, development, and implementation of a rural intersection surveillance and data acquisition system. Gap acceptance behavior of drivers at a live intersection has been quantified, and 2 crashes have been captured.
4. A task analysis, design study, and simulator-based evaluation of innovative Driver-Infrastructure Interface (DII) concepts for communicating to the stopped driver, leading to an understanding of the timing and content of information needed for an effective, acceptable DII.

Each of these is expanded in the sections that follow.

1. Review of Minnesota's Rural Intersection Crashes: Methodology for Identifying Intersections for Intersection Decision Support (IDS)

Contributors: Howard Preston, Richard Storm, Max Donath, Craig Shankwitz

Minnesota's rural crash records were analyzed in order to develop a better understanding of crashes at rural intersections and their cause. The study's objective was to investigate the causes of crashes at rural intersections and to support the development of technology based strategies to mitigate the high crash rate. Since previous research found that up to 80 percent of intersection crashes at thru-STOP intersections may be related to selection of insufficient gaps in traffic, the development and validation of Intersection Decision Support (IDS) technology that assists in proper gap selection was identified as a primary goal. This was also supported in *National Cooperative Highway Research Program* (NCHRP) *Report 500 (Volume 5): A guide for Addressing Unsignalized Intersection Collision,* which was written in response to AASHTO's SHSP to provide state and local agencies with tools to address crashes at unsignalized intersections. Objective 17.1 D1 states that there is a need to "Provide an Automated Real-Time System to Inform Drivers of the Suitability of Available Gaps for Making Turning and Crossing Maneuvers".

This portion of the investigation addressed questions such as: how many unsafe rural intersections are there in Minnesota, where they are, and what are the characteristics of crashes at these intersections. Without a comprehensive understanding of Minnesota's rural intersection crashes, effective deployment of IDS technology would be difficult, especially if the hypothesis that drivers have difficulties selecting adequate gaps is invalid.

A database of over 3,700 intersections was examined. Using the critical crash rate as an indicator, 23 rural expressway intersections and 104 rural two-lane intersections were identified as unusually "dangerous" locations. Of these 127 intersections, further investigation focused on the rural expressway intersections, since expressways tend to carry higher volumes at higher speeds when compared to two-lane roadways. Also, past studies found that the percentage of intersection crashes on rural expressways increases with increasing mainline volumes, and there are several high-volume rural expressway corridors in Minnesota.

This study of Minnesota intersections showed that crashes at rural expressway thru-STOP intersections have similar crash and severity rates when compared to *all* rural thru-STOP intersections. However, right angle crashes (which are most often related to gap selection) were observed to account for 36 percent of all crashes at the rural expressway intersections. At intersections that have higher than expected crash rates, approximately 50 percent of the crashes are right angle crashes (This 50% figure is up from the 28% for all rural thru-STOP intersections). Further investigation also found that drivers' inability

to recognize the intersection, and consequently run the STOP sign, was cause for only a small fraction of right angle crashes, whereas gap selection was the predominate problem.

This is consistent with other findings; Chovan et al. (1994) found that the primary causal factors for drivers who stopped before entering the intersection were:

1. The driver looked but did not see the other vehicle (62.1 %),
2. The driver misjudged the gap size or velocity of the approaching vehicles (19.6 %),
3. The driver had an obstructed view (14.0 %), or
4. The roads were ice-covered (4.4 %).

Of these four driver errors, the first three can be described as either problems with gap detection or gap selection.

The rural Intersection Decision Support (IDS) system described in Section 2 should provide a driver with assistance in selecting and identifying an appropriate gap.

As a result of the above analyses, a specific intersection was selected for testing an IDS system which tracks the gaps between vehicles and communicates the appropriate information to drivers who are stopped and waiting to enter the intersection.

If the IDS technology proves to be effective at reducing gap-related intersection crashes, a system-wide deployment to all rural thru-STOP intersections is not likely due to the large number of rural intersections in Minnesota. If the goal was to specifically target fatal crashes, only seven rural thru-STOP intersections in Minnesota had two fatal crashes during the analysis period (3 years) and no intersections had three or more fatal crashes. Further, of the 590 fatal crashes that occurred in 2002, only 8 percent occurred at rural thru-STOP intersections on the state highway system. This information lends support to the need for a systematic deployment of the technology since a crash frequency based deployment would be ineffective and a system-wide deployment is not financially feasible. One approach to a systematic deployment would be to deploy the IDS system at the 127 "dangerous" locations identified earlier. This approach could potentially eliminate 270 crashes per year with an annual crash cost of almost $26 million.

For more information, see the full report on the crash analysis and the methodology (Preston et al., 2004).

2. *Statistical Modeling for Intersection Decision Support*

Contributors: Gary A. Davis, Nebiyou Tilahun, Paula Mesa

The statistical modeling component of the Intersection Decision Support (IDS) project consisted of four main objectives:

1. Identify stop-controlled intersections on Minnesota's rural expressways whose crash experience makes them candidates for (future) IDS deployment;
2. Develop a method for estimating the crash reduction effect of the IDS deployment at United States Trunk Highway (USTH) 52 and Goodhue County State Aid Highway (CSAH) 9, even though selection bias will be present;
3. Develop a method for predicting the crash reduction potential of the IDS deployment for input into a first approximation of a cost/benefit analysis;
4. Test the hypothesis that older drivers are over-represented in intersection crashes along USTH 52, and identify other rural expressway intersections where older drivers might be over-represented.

This study pursued a more comprehensive statistical analysis than was possible with the critical crash rate used for identifying intersections for instrumentation. To accomplish this, a hierarchical statistical model similar to that employed in FHWA's Interactive Highway Safety Design Model was developed, using crash, traffic and roadway data for 197 four-legged, two-way, stop-controlled intersections on Minnesota rural expressways. Both major and minor approach average daily traffic turned out to be important predictors of crash frequency, while the number of major approach driveways had a weaker effect.

The model was then used to identify intersections whose expected crash frequency exceeded, with high probability, what would be typical for rural expressway intersections with the same traffic volumes. The five intersections so identified formed a subset of the 23 potentially high-hazard intersections identified in an earlier report, which used the critical rate method. The intersection of USTH 52 and CSAH 9, in Goodhue County, was one of the five we identified as showing an atypically high expected crash frequency. An aerial view of this intersection is shown below in Figure 1below.
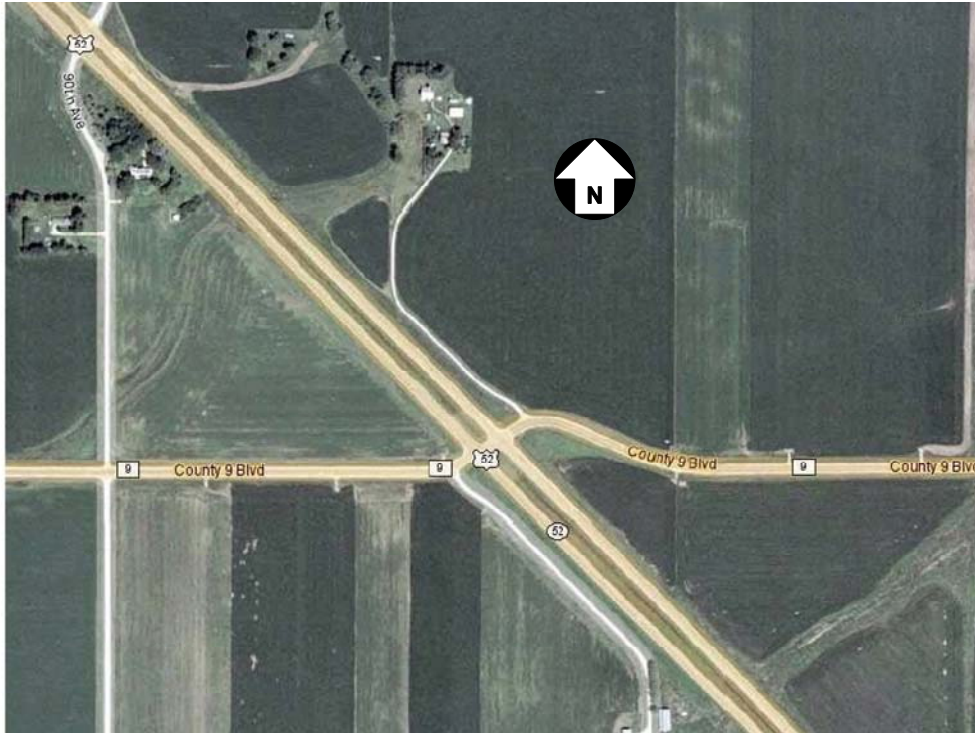
Figure 1. Aerial view of Minnesota Test intersection at US 52 and

Goodhue County 9 south of Cannon Falls, Minnesota

It was next possible to consider a plausible range of hypothetical crash counts occurring after deployment of the IDS at USTH 52 and Goodhue CSAH 9 and use these hypothetical counts to compute Bayes estimates of the IDS accident modification factor. Our results suggested that a three year 'after' period at this single intersection would probably be sufficient to detect whether or not the IDS had a beneficial effect, but that estimating the magnitude of this effect would be more difficult.

Our statistical model was then used to predict potential crash reduction benefits of a wider IDS deployment, on the assumption that the IDS would reduce the crash propensity at a high crash location to what would be typical for similar intersections. Over a 15 year period, deployment of the IDS at the five high crash intersections identified earlier would result in a reduction of about 308 crashes.

Finally, an induced exposure approach was used to identify intersections where older drivers appear to be over-represented. Twelve such intersections were identified, with five of them being on USTH 52. This last result should be interpreted cautiously however since the possibility that older drivers are differentially more prevalent on minor approaches has not been discounted.

For more information, see the full report on the statistical models (Davis et al., 2005).

3. Intersection Decision Support Surveillance System: Design, Performance and Initial Driver Behavior Quantization

Contributors: Lee Alexander, Pi-Ming Cheng, Max Donath, Alec Gorjestani, Arvind Menon, Craig Shankwitz

The Minnesota Rural IDS system is meant to provide a driver the information needed to make correct decisions regarding the available gap. The system is designed to provide the safety benefits of a signalized intersection (fewer crashes, opportunities for all drivers to enter/cross the traffic stream, etc.) while minimizing the downsides (expense of installation, disruption of traffic flow, etc.). It should be noted, however, that the IDS system will not provide additional opportunities for drivers to enter/cross the traffic stream because unlike a traffic signal, it will not create gaps that were not already there.

The IDS system consists of four distinct components: sensors, computer processors, a communication subsystem and a driver interface. The sensors, computer processors, and the communication subsystem are used to determine the "state" of the intersection; a driver interface conveys timely, appropriate information to the driver waiting on the minor road. Sensors, processors and communication systems are addressed in this section; the driver interface is described later in Section 4.

Mainline state information includes the location, speed, acceleration, and lane of travel of each vehicle within the surveillance zone. The state information combined with known intersection geometry facilitates the real time tracking of traffic gaps on the mainline. Minor road state information includes the position and speed of the vehicle on the minor road, and an estimate of the classification of the vehicle. Present classification separates vehicles into four categories: Motorcycle/passenger cars, SUV/light truck, medium duty truck/school bus, and heavy-duty truck/semi/motor coach/farm equipment.

A central processor computes the "state" of the intersection at 10 Hz. Should an unsafe condition be detected by the threat assessment algorithm, the central processor initiates the proper warning to the driver through an infrastructure-based interface known as the Driver-Infrastructure Interface, or DII. (For this phase of the project, a DII was not located at the test intersection. It will be installed and tested in a subsequent phase of the project.) The system was designed as an infrastructure based system, but will support cooperative systems as well. Figure 1 below illustrates the concept, showing schematically the sensors, the communication and the computation systems (a central processor located in a road side unit) all arranged at the selected intersection.

A prototype rural IDS system was designed and installed at the intersection of US 52 and County State Aid Highway 9 in Goodhue County, MN. This system was designed to serve two purposes:

First is to characterize driver behavior in terms of gaps selected by drivers under various traffic, weather, vehicle, and seasonal conditions. Understanding driver behavior in these conditions is critical to the development of a Driver-Infrastructure Interface that will provide a driver the needed information at the proper time. Preliminary data has shown

that most drivers select gaps less than those recommended by AASHTO; the actual mean selected gap is on the order of 6 seconds.   AASHTO recommendations are summarized in Table 1below.

Table 1. Time gaps for stop controlled intersections taken from (AASHTO, 2001). Note that even within (AASHTO, 2001), discrepancies exist as to what dictates an acceptable time gap. Variation of this value demonstrates uncertainty determining an acceptable gap

| Design Vehicle	Time gap(s) at design speed of major road for a stopped vehicle *to turn right* or left onto a two-lane highway with no median and grades of 3% or less.	Time gap(s) at design speed of major road for a stopped vehicle *to turn right* onto or cross a two-lane highway with no median and grades of 3% or less.
Passenger car	7.5 s	6.5 s
Single-unit truck	9.5 s	8.5 s
Combination truck	11.5 s	10.5 s
Adjustments	Multilane Highways: for left turns onto two-way highways with more than 2 lanes, add 0.5 seconds for passenger cars, and 0.7 seconds for trucks for each additional lane, from the left, in excess of one, to be crossed by the turning vehicle.	Multilane Highways: for left turns onto two-way highways with more than 2 lanes, add 0.5 seconds for passengers cars, and 0.7 seconds for trucks for each additional lane to be crossed and for narrow medians which cannot store the design vehicle.
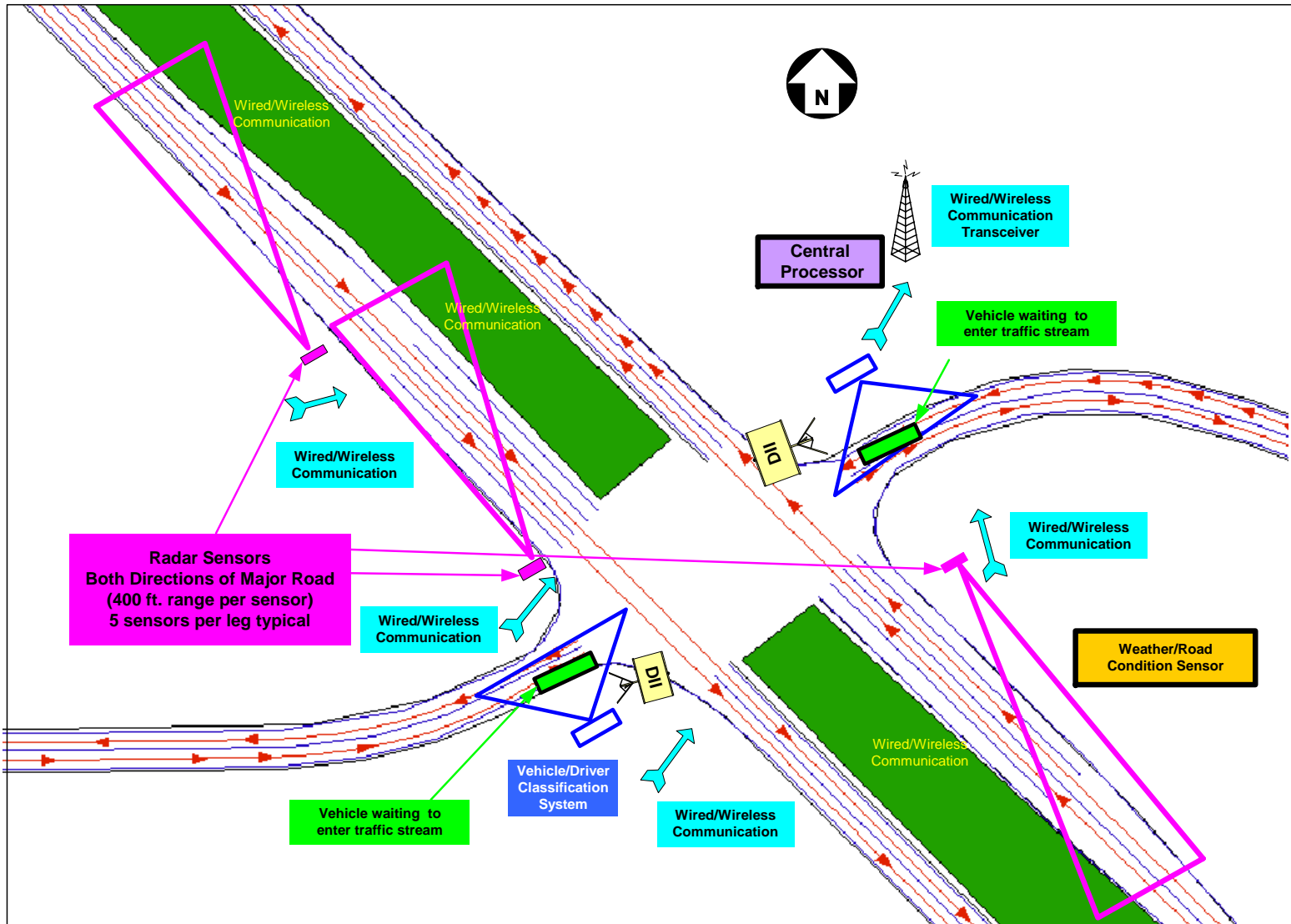
Figure 2. Layout of Rural IDS System

This information is critical if an effective, safe driver interface is to be deployed.

Second, the intersection will serve as the initial deployment location for testing of the IDS system, including the driver interface. The rich data set collected by the instrumentation deployed at this intersection will enable a comprehensive "before" and "after" analysis so that the benefits of the system can be clearly demonstrated and quantified.

3.1 Sensor components and design

Four sensor groups are used in this IDS system. The first group of sensors is based on radar, and is located along the mainline of the intersection. Radar, in general, provides the optimal solution in terms of tracking ability (including lane assignment), coverage area, range, accuracy, angular resolution, and cost.

The second sensor group provides information needed to classify vehicles (and possibly drivers) on the minor roads. Vehicle classification is required because of the variation of the dynamic capability of highway vehicles entering the intersection from the minor road.

The third sensor group provides information needed to measure the trajectories of vehicle in the crossroads (or median) of the intersection. The primary questions to be answered by collecting this data are whether drivers consistently stop in the median area to make a second gap decision, and whether gap selection behavior is different for vehicles waiting in the crossroads.

The fourth sensor group measures other factors that may influence the conditions or rate at which the traffic stream is entered or crossed. For instance, a comprehensive road/weather condition sensor provides an indication of visibility and tire-road friction characteristics. This information can be correlated with gap acceptance data to better define gap warnings and advisories.

3.2 Communication systems

At the present time, both hardwired and wireless communication is supported. A DSL modem is used to ensure reliable, 16.7 Mbps hardwired communications over the long distance between the radar stations and the main controller cabinet. In addition to wired communication, each sensor station is equipped with an 802.11b wireless transceiver. Wireless communication is included so that cost:benefits of both hardwired and wireless systems can be validated as a means to establish an optimal deployment path.

3.3 Computation Systems

A number of algorithms are used in the rural IDS system. The first of note are the radar processing algorithms. These algorithms transform target information from the radar coordinate frame to the road's coordinate frame, and filter out false targets by comparing target location to the local landscape using an on-board geospatial database. The geospatial database is a high accuracy (decimeter level) georeferenced system that

provides all feature and attribute information in real time to the embedded computing system in a format that is significantly different than the digital map used for navigation. Some might call it an enhanced digital map, but its architecture is intentionally different.

Analogous to the radar processing algorithms are the vehicle classification algorithms, which use laser scanner (lidar) information to assign a vehicle a classification category based on the side profile of the vehicle. This information is then sent to the central processor.

An estimator-based vehicle tracker assigns each vehicle entering the intersection a unique ID, and determines location, speed, and lane of travel as long as the vehicle remains within the intersection (a 1220m (4002 ft) x 244m (800 ft) area). Gap tracking uses the vehicle tracking results and known intersection geometry to determine the location, length, and speed of the available gaps. Gap data will be used to trigger the driver interface.

3.4 System Performance Summary

In Table 2 the performance of the rural IDS surveillance system is summarized. These results were documented prior to February 16, 2005, which is when the system was turned on, to subsequently measure and assess driver gap selection and intersection entry behavior. It should be noted that the system is "overbuilt", and designed to be a reference system. Subsystems can be degraded in the future to support benefit:cost studies. Definition of limits of acceptable performance will result in the overall system performance specifications necessary to finalize a deployable system design.

Table 2. Mainline radar-based surveillance system performance summary

Measure	Value	Method used to test system
Detection rate	> 99.99%	Multiple sensor observations over 5 days, one missed target
Location accuracy	< 7 meters	High speed tests with DGPS equipped probe vehicle as reference
Speed accuracy	1.6 kph	High speed tests with DGPS equipped probe vehicle as reference
Lane assignment accuracy	95%	High speed tests with DGPS equipped probe vehicle as reference. (Ambiguity arises from lane change events.)

Table 3 summarizes the performance accuracy of the lidar-based vehicle classification system. A misclassification error of one-category is defined as the misclassification of a vehicle category that is one category adjacent to the correct one. For example, if classes 1 (small passenger vehicles), 2 (large passenger vehicles), 3 (small commercial vehicles) and, 4 (large commercial vehicles) are available, a "2" class vehicle identified as a "3" class is a one-category error; "2" class identified as a "4" class represents a two-category error.

Table 3. Performance summary of the lidar-based vehicle classification

operating on the minor road

Measure	Value	Method
Detection rate	> 99%	Human observation, no missed vehicles detected
Misclassification rate	<5%	Errors of one classification category
	<1%	Errors of two classification categories

3.5 Driver Behavior Summary

Data to determine driver gap decision making behavior at the test intersection was collected once the system was turned on in February 2005. The definition of accepted gap chosen for this study is the point in time at which the rear of the minor road vehicle has vacated the minor road. At that time, the gap time is defined as the time it would take the closest vehicle to reach the middle of the intersection if its speed and acceleration were held constant. For right turns and for passage into the median, only vehicles approaching from the left are used for determining the gap. For vehicles in the median, only vehicles approaching from the right are considered for the gap. Gap statistics for all accepted gaps for February and March 2005 using this definition are shown in Table 4.

The mean accepted gap for every measurable driver maneuver was 10.2 seconds and the median was 9.7 s. The standard deviation was 4.1 s. For vehicles that accepted a gap less than 10 seconds, the mean accepted gap was 7.0 s and the median was 7.2 s. (If traffic volumes on the mainline are low, it is often the case that vehicles approaching the intersection are so far away that the minor-road driver does not really make a gap decision. The presence of these large gaps can skew the distribution of accepted gaps. By limiting the sample population to gaps of less than 10 seconds, the skew is removed, providing a better indication of gap acceptance decisions, under more difficult conditions.) Moreover, 95% of drivers selected a gap greater than 4.4 seconds while 99% accepted a gap greater than 3.1 seconds.

Table 4. Gap statistics for all accepted gaps between February 1 and

March 29, 2005

Total Measured Gaps	Gaps < 10s	Mean Gap		STD		50% Gap		95 % Gap		99% Gap	
		All	<10s	All	<10s	All	<10s	All	<10s	All	<10s
9108	4808	10.2	7.0	4.1	1.9	9.7	7.2	4.4	3.8	3.1	2.8

Gaps were also measured based on whether the minor road vehicle was crossing/merging with northbound or southbound traffic. This analysis showed that the gaps were significantly smaller for vehicles crossing/merging the southbound lanes of US Highway 52 than for vehicles crossing/merging the northbound lanes. The average traffic volumes for northbound and southbound lanes are similar, but the traffic patterns are very

different. Two signalized intersections eight miles north of the intersection in Cannon Falls cause the southbound traffic to arrive at the intersection in waves. This causes drivers to select smaller gaps when vehicles arrived in bunches because there were no large gaps available. At other times, there were no vehicles detected on the mainline so no measurable gap was recorded. The northbound lane exhibited a more steady flow of vehicles. Since the available gaps were larger and measurable, the mean accepted gap was higher.

The accepted gaps were also analyzed based on time of day. The statistics in Table 5 show that the smallest gaps were accepted in the evening rush hour. The zone indicates the location of the decision-making driver/vehicle. Zone 1 represents the area on county road 9 west of the intersection; Zone 2 represents the area on highway 9 east of the intersection. Zone 7 and 8 the area within the median, traveling east and west, respectively.

Analysis shows that the accepted gap was inversely related to the traffic volume. Traffic volume increased throughout the day and was heaviest in the evening rush hours and lightest at night.

Table 5. Statistics for accepted gaps as a function of time of day

Right turn/ Strght thru	Time Period	Total Gaps	Gaps < 10 s	Mean Gap		STD		95 % Gap		99% Gap	
				All	<10s	All	<10s	All	<10s	All	<10s
Rt. Turn	A.M. Rush	1143	344	12.3	7.5	4.0	1.7	5.8	4.4	4.0	2.6
Rt. Turn	Day Time	2305	933	11.4	7.5	4.1	1.8	5.0	4.0	3.3	2.9
Rt. Turn	P.M. Rush	1191	514	11.1	7.3	4.2	1.8	4.7	4.0	3.2	2.7
Rt. Turn	Night Time	447	106	13.0	8.1	3.8	1.5	7.0	4.8	4.8	4.0
Strght-thru	A.M. Rush	1427	857	9.6	7.0	3.8	1.8	4.3	4.0	3.3	3.0
Strght - thru	Day Time	4548	2754	9.4	7.0	3.8	1.9	4.2	3.7	3.0	2.7
Strght - thru	P.M. Rush	2250	1526	8.9	6.8	3.8	1.9	4.1	3.8	2.9	2.7
Strght - thru	Night Time	642	339	10.2	7.1	4.1	1.8	4.5	4.0	3.5	3.0

For vehicle type (classification) there was little difference between the accepted gap of larger vehicles and smaller vehicles. This was somewhat surprising since it would be expected that larger vehicles would need larger gaps due to their limited acceleration capabilities and their length. The definition of gap used in this work does not measure when the driver decided to take the gap, but when the driver was already committed and in the middle of the mainline lanes. This tends to normalize the accepted gap with respect to vehicle size because the definition does not measure the time it took for the vehicle to enter the major stream of traffic, which is a function of acceleration and

vehicle length. The end result was that drivers of larger vehicles had a similar risk tolerance as drivers of smaller vehicles because they ended up in the middle of the intersection at the same gap time. This phenomenon is explained further in the more detailed report; a new definition of gap may be required to support further analysis. Additional sensors may also be required to more accurately measure the point at which the driver initiates his maneuver.

The accepted gap varied based on the maneuver made by the vehicle at the minor road. The average accepted gap was largest for left hand turns, followed by right and straight through maneuvers. This was expected as it takes longer to perform a right and left turn because the vehicle must accelerate up to the mainline speed while the straight crossing maneuver only requires crossing the length of the lanes.

Table 6. Gap statistics for different maneuvers

Maneuver	Total Gaps	Gaps < 10 s	Mean Gap		STD		95 % Gap		99% Gap	
			All	<10s	All	<10s	All	<10s	All	<10s
Straight	6104	3724	9.4	6.9	3.9	1.9	4.1	3.7	3.0	2.8
Right	2945	1064	11.8	7.5	4.1	1.8	5.3	4.2	3.6	2.9
Left	59	20	12.7	6.8	5.0	1.7	4.4	4.2	4.2	4.2

For vehicles waiting at the stop bars on country road 9, the gap accepted decreased the longer they waited. This is due to the fact that they were waiting because there were not any acceptably large gaps. The drivers did not significantly increase their risk as the means for gaps of less than 10 seconds were similar for all waiting times.

For vehicles waiting at the median the result was different. Vehicles spending the least amount of time in the median and the vehicles spending the most time in the median chose the smallest gaps. Half the vehicles spent less than 3.6 seconds in the median.

The accepted gap data was cross-correlated with weather data collected one mile from the intersection. The average accepted gap increased for decreasing visibility and increasing precipitation rates. The average speed on the main line decreased slightly during weather events which could explain the increase in accepted gaps. Drivers chose safer gaps when the weather conditions worsened.

Finally, an analysis was done on small accepted gaps; those less than four seconds. The analysis showed that 3.2% of drivers accepted a gap of less than four seconds. Also, an over representation of small gaps was found for straight through maneuvers and for vehicles entering/merging the southbound lanes of Hwy 52. The vehicles crossing the southbound lanes of Hwy 52 from the median showed the greatest over representation of small gaps. This maneuver type exhibits the most unsafe gap selection behavior at the test intersection.

For more information, see the full report on the surveillance system and the driver gap decision making behavior (Alexander, et al., 2005).

4. A Simulator-based Evaluation of Driver Infrastructure Interface Concepts for Intersection Decision Support at Rural Thru-STOP Intersections

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This section describes the human factors basis for an intersection decision support (IDS) system intended to improve the safety of rural intersections in Minnesota's Interregional Corridors (IRCs). The purpose of the human factors effort is to understand the task of rural intersection negotiation, identify high-risk user groups, describe the human factors that contribute to intersection accidents, and determine what conceptual types of information to present in the IDS display to improve driver performance and safety. Consistent with the original infrastructure consortium proposal, this report emphasizes gaps, older drivers, and rural thru-STOP intersections (Preston, Storm, Donath & Shankwitz, 2004). This is because older drivers have a high accident risk at rural thru-STOP intersections and problems with gap detection, perception, and acceptance are contributing factors.

4.1 Introduction

Older drivers are 65 years of age and older. A rural thru-STOP intersection consists of a two or more lane highway intersection by a STOP-controlled minor road. A gap is the time or distance between successive vehicles in a traffic stream and a lag is the remaining part of a gap after a driver first arrives at an intersection. An acceptable gap is one that a driver indicates is acceptable for the intended maneuver (crossing or turning). An accepted gap is one that is actually accepted and crossed by a driver. A safe gap (t_G) is based on an objective model that considers both driver perception response time (t_{PRT}) and maneuver time (t_{MT}). It is the minimum gap size needed to execute a maneuver without causing a conflict. If the IDS system advises drivers about the acceptability of gaps, it needs to make recommendations based on safe gaps. This is because accepted and acceptable gaps are subject to driver perceptual and decision making errors (Lerner et al., 1995).

4.2 Task Analysis

Based on a task analyses for negotiating a (stop-controlled) intersection, drivers are expected to complete the following tasks at rural intersections in an approximate temporal order:
- Detect intersection
- Decelerate
- Enter correct lane (if required)
- Signal if intending to turn
- Detect traffic control device (signs or signals)
- Interpret traffic control device
- Monitor lead vehicle (if present)
- Detect traffic and pedestrians
- Detect, evaluate, and monitor gaps in traffic

- Accept gap and complete maneuver
- Continue to monitor traffic and control device until intersection is cleared

4.3 Driver Errors

Driver errors made at intersections, including those most likely to cause problems for older drivers are summarized below:
- Failure to detect intersection
- Failure to slow adequately before entering intersection (older driver error)
- Failure to change lanes properly (older driver error)
- Failure to signal or wrong signal (older driver error)
- Failure to detect traffic control device (older driver error)
- Failure to obey traffic control device
- Failure to comprehend traffic control device (older driver error)
- Failure to check sight lines obscured by lead vehicle
- Failure to estimate velocity, distance, or gap to lead vehicle (older driver error)
- Failure to detect traffic and pedestrians (older driver error)
- Failure to anticipate actions or intentions of other drivers and pedestrians
- Failure to estimate velocity, distance, or gap between other vehicles (older driver error)
- Failure to consider all factors when accepting gaps
- Failure to clear intersection

4.4 Design Process & Options

The design process for identifying key concepts and features required in an IDS system are outlined below. An abstraction hierarchy (AH) analysis for intersection negotiation identified a number of environmental constraints and information elements for the IDS concepts that were proposed. The skills, rules, knowledge (SRK) framework and an analysis of information processing in the Driver Error section (Laberge et al., 2003) were used to identify the operator (driver) constraints. This helped ensure the information content was represented in a form that is consistent with driver performance and information processing limitations (Lee et al., 2003). The ecological approach was a suitable supplement to the traditional task analysis method used to identify driver tasks (Laberge et al., 2003) and helped to identify new information requirements.

Potential information concepts for each driver task involved with negotiating a rural thru-STOP intersection are described in more detail in the full report. Information requirements are not limited to the IDS system and also include changes to the intersection and in-vehicle solutions that can convey important information to drivers. Primary content elements directly support minor-road driver tasks related to gap detection, perception, and judgment. Secondary content either supplements or draws attention to specific information to help minor-road drivers make more efficient (rather than accurate) decisions. General limitations and design premises were identified to better define the boundaries for potential IDS solutions.

Gap specific design issues were related to identifying and highlighting vehicles and gaps at the intersection to help drivers make better decisions. Behavioral attributes of the driver and how drivers make gap acceptance decisions were also identified to explain how drivers may perceive or interact with an IDS system. A specific consideration for non-cooperative infrastructure IDS systems is that they must take into account the worst-case scenario of an older driver attempting to turn or cross at the intersection.

4.5 Design Concepts

Based on the preceding design process and a review of existing infrastructure-based systems applicable to IDS, a preliminary set of design concepts was generated (listed below; see Table 7). These interface concepts include systems that provide alerting information, as well as systems that display gap-specific information, warn about unsafe actions and advise against unsafe actions at the intersection. The safe gap thresholds for all candidate interfaces take into account the worst-case gap acceptance scenario of an older driver making a left turn.

- Hazard Concept: A flashing yellow "Dangerous Traffic" message alerts drivers to the presence of traffic on the main roadway.

- Countdown Concept: Two signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) provide drivers with a timer countdown indicating how far away (in seconds) approaching traffic is for each set of lanes and also uses icon messages to indicate prohibited actions (i.e., do not cross or turn left).

- Icon Concept: Two identical signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) provide warning indicators about approaching traffic and prohibitive message for each set of traffic lanes.

- Variable Message Sign Concept (VMS): Two identical signs (one at the STOP sign for near-side traffic; one in the median for far-side traffic) use icon messages to indicate prohibited actions (i.e., do not cross or turn left). The logic is the same as the Countdown concept, but does not include the timer countdown.

Table 7. Matrix of interface concepts highlighting information elements

and role of driver

	No Support	Hazard Detection	Gap Information		
	Baseline	**Alert**	**Display**	**Warn**	**Advise**
Design Concept	STOP Sign (no support)	Hazard Sign	Countdown Sign	Icon Sign	Variable Message Sign (VMS)
Driver Role	Driver recognizes hazard, gathers information, decides on safety condition and chooses action.	Driver gathers information, decides on safety condition, and chooses action.	Driver decides on safety condition and chooses action.	Driver must choose action.	Driver chooses to comply.
System Role		System detects hazard and provides alert.	System detects hazard and presents information relevant to vehicle gap. Prohibited actions also indicated.	System detects hazard and provides warning levels based on gap information. Prohibited actions also indicated.	System displays prohibited actions (unsafe action advisory).

4.6 Concept Evaluation Study

The methodology and results of a simulator-based evaluation study to test the information concepts of the designs is explained below. The concepts presented to drivers in this study do not necessarily represent the final designs, but instead will be modified based on the results of the study. The sign concepts were tested with a group of older drivers (age 55-75) and compared to results from a group of younger drivers (age 20-40). The sign concepts were tested in both high (day) and low (night) visibility conditions. The crossroads of US 52 and CSAH 9 in Goodhue County, MN were modeled in the simulation to test the sign concepts.

The Icon concept sign resulted in the largest mean accepted gap, which was significantly larger than the other three sign concepts and baseline (i.e. the existing sign at the intersection). The Icon design had the highest comprehension rates for drivers in all conditions, and was rated as the second most useful and satisfying of the IDS signs by all

young drivers and old drivers in the night condition. Some drivers, particularly old drivers in the day condition, found the complexity of the sign to be confusing.

The Countdown sign resulted in an accepted gap that was significantly different from the baseline; however the gap value was not significantly different from the Hazard or VMS accepted gaps. This sign's design had the second highest comprehension rates and was the most preferred design for all young drivers and for old drivers in the night condition. These groups also rated the Countdown sign as the most useful and satisfying of all the IDS concepts. A majority of drivers reported using information from the Split-hybrid sign while making their crossing decisions, particularly in the night condition.

The VMS sign resulted in an accepted gap that was significantly larger than baseline. The VMS sign had the lowest comprehension rate of the sign concepts. It was ranked similarly to the Hazard sign for usability, and below the Countdown and Icon signs.

The Hazard sign resulted in an accepted gap significantly larger than baseline. Most drivers identified the sign as an alerting system and it was most preferred by old drivers in the day condition.
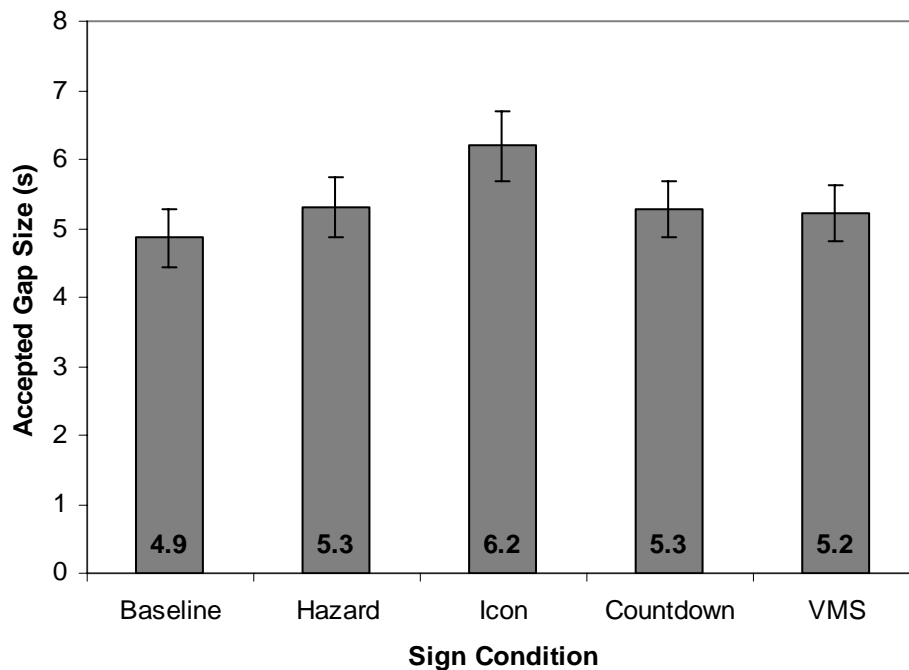

Figure 3. Mean gap by sign

The safe gap threshold was perceived to be conservative by many drivers. This most likely occurred because it was based on the worst-case scenario of an old driver making a left-turn maneuver. A single, global threshold for an IDS system is most likely not sufficient in terms of practicality and user acceptance.

Overall, the sign concepts that provided continuous, dynamic information about the intersection were better comprehended than those that did not. For example, the Icon and Countdown signs change dynamically as traffic approaches. In contrast, the VMS sign only changes when a gap above the safe gap threshold is detected, thus appearing static to drivers and making its function more difficult to interpret.

4.7 Recommendations and Design Limitations

The informational content of both the Icon sign and the Countdown sign were best understood by drivers and more frequently used to make crossing decisions. There are certain limitations associated with each sign. First, both must be altered to include MUTCD compliant sign content. Second, safe gap thresholds that are individualized to the driver may increase the usability of the signs' content and should be evaluated. Other issues that need to be considered include the way drivers interpret and interact with a prohibitive message, as used in the current implementations and how best to educate drivers on the function and utility of such a support system.

4.8 Future Research Needs

- Expanding design options beyond alerting and information alone and including the full spectrum of intervention, such as notification, enforcement and automatic control.
- Develop MUTCD compliant variants of the IDS concepts for future deployment and testing.
- Develop and test "do not enter" symbols for use with the Countdown sign that do not conflict with other traffic signs in the same area with a different function.
- Investigate and test alternate ways for presenting time-to-arrival information to drivers.
- Continue to investigate how drivers interpret the disappearance of prohibitive information and the presence of cautionary information.
- Investigate how best to disseminate information about the function of the IDS signs to drivers and how best to educate users on the purpose of the sign to better encourage usage, particularly among old drivers who may not be aware of their increased crash risk at intersections.
- Develop parameterized models to predict discrepancy between safe and accepted gaps (safety margins) to dynamically target IDS functions to at risk drivers and intersection situations.
- Future research should test drivers in more complex gap situations. Some of the factors that should be evaluated include multiple vehicles on different paths and when a driver is approaching an intersection as opposed to stopped.

For more information, see the full report on the simulator based evaluation (Creaser et al., 2005).

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