RESEARCH PROSPECTUS:

Reducing Crashes at Rural Intersections: Toward a Multi-State Consensus on Rural Intersection Decision Support

This prospectus describes a proposal to develop countermeasures to mitigate vehicle crashes at rural highway intersections. This research will build on recent advances in intelligent transportation systems (ITS) technology to address a significant public safety problem. The proposed Intersection Decision Support (IDS) system to be developed represents a radical and innovative solution to a problem with far-reaching implications for the safety and mobility of the driving public.

Rural Intersection Decision Support focuses on enhancing the driver's ability to successfully negotiate rural intersections. It is a system which will use sensing and communication technology to determine the safe gaps and then communicate this information to the driver so that he or she can make an informed decision about crossing the intersection or entering a major road traffic stream. Our goal is to reduce crashes and fatalities at such intersections without having to introduce traffic signals which on high speed rural roads often lead to an increase in rear end crashes.

The State of Minnesota is already partner with California and Virginia in a pooled fund consortium (the Infrastructure Consortium) dedicated to improving intersection safety. Three research teams have been identified: The Intelligent Transportation Systems Institute at the University of Minnesota, the PATH (Partners for the Advancement of Transit and Highways) Program at the University of California's Berkeley campus, and the Virginia Tech Transportation Institute at Virginia Polytechnic. Each member of the consortium is tasked with addressing an aspect of intersection safety; Minnesota's efforts focus on the problem of rural intersection crashes.

The Minnesota objective is to develop a better understanding of the causes of crashes at rural intersections and then develop a toolbox of effective strategies to mitigate the high crash rate. Preliminary information seems to point to the driver's inability to correctly identify and select the gap needed for safe passage. Efforts proposed in this program address rural intersection crashes through the application of a suite of advanced surveillance technology, algorithms which predict vehicle motion, and driver interfaces designed to best provide necessary information to drivers at intersections. 'Low tech' solutions will also be considered. The main program emphasis is on the integration of these key components into an effective, affordable system. We will consider alternatives to traditional traffic signals as a means to decrease the frequency and severity of rural intersection crashes.

Rural highway intersection collisions are a common problem faced by Departments of Transportation across the United States. The Minnesota research team is actively seeking the participation of other state DOT's whose perspectives and insights can help build a workable and deployable system for rural areas. The objective of this state pooled fund is to reach a multi-state consensus on the nature of a proposed rural intersection decision support system. The Minnesota DOT will serve as the lead agency for this effort. The Infrastructure Consortium (i.e. Minnesota, Virginia, California, and the Federal Highway Administration (FHWA)) has already committed $2,129,000 over three years to the rural intersection program; we are seeking an additional $70,000 per state over the course of these three years (or $23,333. per year) from other states for a related project.

The focus is on driver error at rural intersection crashes which involve a driver on a minor roadway failing to select a proper gap in the traffic stream when trying to cross a high-speed, high-volume highway at a through/stop intersection. This problem was identified by the unsignalized intersection panel of NCHRP Study #17-18(3) which developed guidelines for the implementation of the AASHTO Strategic Highway Safety Plan [Neuman, Pfeffer et al., 2003]. In their report which identifies objectives and strategies for dealing with unsignalized intersections, the panel described Objective 17.1D Improve Availability of Gaps in Traffic and Assist Drivers in Judging Gap Sizes at Unsignalized Intersections, in effect outlining a similar objective to ours. The report specifically suggests that a strategy be developed to "Provide an Automated Real-Time

System to Inform Drivers of the Suitability of Available Gaps for Making Turning and Crossing Maneuvers (Strategy 17.1 D1)

This separate pooled fund project will specifically focus on (a) identifying the relevant rural intersection crash problem in each of the member states, (b) reviewing and reaching a consensus on the nature of a new approach to communicating the intersection conditions to the driver, i.e. a new ‘interface’ that allows the driver to make better decisions about entering the intersection, (c) consideration of a test intersection in each state, and (d) working with member states to bring their test intersection into a national demonstration of the new system.

Each state that contributes to the pool will have a member on the advisory board guiding the research. Members of the advisory board are expected to interact with the researchers—enabling the advisory board to be the first to assimilate the lessons learned from this groundbreaking work. Intersection Decision Support research represents a direct investment in the future of your state’s transportation system and the drivers who depend on it.

Rural highway intersection crashes: a national problem

The National Safety Council estimates that 32 percent of all rural crashes occur at intersections. Moreover, approximately one in four fatal crashes occurs at or near an intersection. Because of the high speeds involved, intersection crashes in rural areas are more likely to result in fatalities than are intersection crashes in urban or suburban areas.

In Minnesota, for example, there are more rural through/stop intersections than any other type of intersection, urban or rural. AASHTO Strategy No. 17, *Improving the Design and Operation of Highway Intersections*, lays out the significance of intersection crashes in its preamble:

> “Injury and fatality statistics for highway intersections and interchanges are ample evidence that strategies to improve the safety of these crash prone areas are urgently needed. About one in every four fatal crashes occurs at or near an intersection, one-third of which are signalized. Safety literature also indicates that the two most prominent crash scenarios

involve left turns and being struck from the rear. Right-angle collisions are a predominant cause of death at signalized intersections."

In a presentation to the TRB Task Force A3A35, Arthur Carter [Carter, 1999] indicated that 85 percent of intersection crashes were due to driver error, with a breakdown as follows:

- 27 percent due to driver inattention,
- 44 percent due to faulty perception, and
- 14 percent due to impaired vision.

In Minnesota, statistics show that although 70% of crashes occur in urban areas, 70% of ***fatal*** crashes occur in rural areas. During the period 1998–2000, 62% of intersection-related crashes with fatalities occurred at rural intersections; we believe this high rate is mirrored in many other states.

The economic and geographic conditions found in Minnesota are shared by many other states. Most midwestern and western states are served by only one or two interstate highways. (Iowa, for instance, has one interstate running north-south, and one running east-west.) It is the other high volume, higher speed roads (called inter-regional corridors in Minnesota) that carry major responsibility for the transport of goods and people in these geographic areas. The primary objective of an Intersection Decision Support system would be to provide drivers on the minor road with information indicating when entry into the intersection is safe while at the same time not impeding traffic flow on the high speed major road. As such, these systems should offer potential benefits to a wide audience of users.

Problems with traffic signals at rural intersections

There is a widespread belief outside of the transportation-management community that traffic signals offer a solution to the problem of intersection collisions. However, recent evaluations of traffic signal installations have revealed that:

- **Traffic signals don't reduce crashes.** The reduction in fatal crashes attributable to traffic signal installation is statistically insignificant. Moreover, the frequency of crashes can be substantially increased on rural roads. This increase can be attributed to an increase in the second most common type of intersection collision (after crossing-path crashes): rear-end collisions. This type of collision is relatively rare where high-speed roadways are not signalized. Although controversial, increasing evidence supports this conclusion as documented in NCHRP Report 500 [Neuman, Pfefer et al, 2003] and described under Objective 17.1 F Choose Appropriate Intersection Traffic Control to Minimize Crash Frequency and Severity and expanded in the section on Avoid Signalizing Through Roads (Strategy 17.1 F1)

- **Traffic signals reduce mobility.** Although signals may reduce delays on low-volume crossing roads, this effect is overshadowed by the increase in delays on high-volume roads which carry far more traffic. In rural areas, these highways are commonly traveled by heavy commercial vehicles which are essential to the rural economy. These vehicles exhibit two characteristics which make them worthy of special mention in regard to traffic signals and intersection collisions. First, heavy vehicles traveling at highway speeds are more difficult to stop and more destructive to other vehicles in intersection collisions. Second, once these vehicles are stopped at a signal, it takes several minutes for them to reach highway speed again; repeated stopping and starting by large vehicles increases the number of traffic flow disruptions on highways, resulting in larger delays for all vehicles.

- **Traffic signals don't solve all problems.** Traffic signals are known to be effective for a narrowly defined set of problems: excessive delay on minor roadways and a high frequency of extremely severe crashes. However, this scenario rarely exists at rural intersections. Even though studies of national crash data, (e.g. [Smith and Najm, 2001] who analyzed all intersections, urban and rural), have shown that crossing path crashes at uncontrolled intersections have the highest fatality rate, this does not necessarily mean that traditional signals are the answer. In fact, [Neuman, Pfefer et al, 2003] specifically make the recommendation to Avoid Signalizing Through Roads (Strategy 17.1 F1) Clearly, new solutions are needed to address the unique problems found at rural intersections.

Intersection Decision Support: technology enhancing safety and mobility

The primary form of driver error at rural intersection crashes involves a driver on a minor roadway failing to select a proper gap in the traffic stream when trying to cross a high-speed, high-volume highway at a through/stop intersection.

This is not a surprise. In an analysis of the five most common pre-crash scenarios (see Figure 1) for all intersections, [Najm, Koopman and Smith, 2001] found that an insufficient gap was the dominant causal factor for crossing path crashes at unsignalized intersections (see Table 1).

Minnesota's Intersection Decision Support efforts address this issue as a primary research focus. Intersection Decision Support is not merely an extension of the traffic signal paradigm of traffic flow regulation. Instead, IDS focuses on enhancing the driver's ability to successfully negotiate unsignalized rural intersections. In practical terms, this means giving the driver information about potentially hazardous intersection conditions so that he or she can make an informed decision about crossing the intersection or entering the major road traffic stream. This information is to be primarily directed at users of lower-speed, lower-volume roads, allowing the high-speed, high-volume roads to move freely.

The first task of a successful IDS system is to monitor the position and speed of multiple vehicles traveling along the highway, and from these observations, predict whether the vehicles will come into conflict with a vehicle attempting to cross the flow of traffic. The surveillance and computational subsystems must be located far enough upstream so that adequate time is available to detect and predict vehicle motion and the locations of the gaps between vehicles when they arrive at the intersection. This information must then be presented to the driver in such a way so that it can quickly be recognized, understood, and incorporated into the decision-making process. The design should consider potential system failure modes and provide a means for handling such.

Human factors in IDS

Intersection Decision Support puts the emphasis on the driver—giving the driver more power to understand the complex conditions surrounding the vehicle. IDS takes aim at driver error—the most common cause of intersection crashes—by eliminating a primary cause of driver error: insufficient or erroneous information. Better information leads to better decision-making.

The ITS Institute's HumanFIRST[1] Program at the University of Minnesota has been home to numerous driving-related human factors research projects. The program's immersive driving simulator offers a highly configurable controlled environment for research into human response and decision-making in the context of motor vehicle operation. Important previous work on many related human-factors issues will provide the foundation for the development of the IDS system.

- **Response times.** The driver, the vehicle, and the roadway are constantly engaged in a complex sequence of interactions, including human response to stimuli and vehicle response to human actions[2]. The speed at which a driver can respond to different types of information presented to them while driving is a significant variable which must be explored; this directly affects the computational requirements for the IDS system.

- **Roadway characteristics.** To make the IDS system deployable in a wide range of environments, system design must also take into account the wide variety of different factors influencing intersection sight lines, including road geometry and topography, vegetation (seasonal or permanent), and buildings, billboard, etc., along the roadway. A variety of solutions may be available – some 'low tech'. One such option might be to simply add lighting 10 seconds (at 60 mph, 880 feet) upstream of the intersection. During the day, the light poles themselves may be markers that the driver can use to help judge the gaps as they pass.

[1] Human Factors Interdisciplinary Research in Simulation and Transportation
[2] Human response times consist of three elements: detection, decision-making and execution. Response times can vary by age and experience. Additionally whether or not the event is expected or unexpected can have the potential to produce a wide range of response times. Furthermore, the response times of the vehicle must also be taken into account.

- **Perception and attention.** Unfamiliar surroundings often lead to misperceptions[3]; for instance, misjudging gaps in the traffic stream or misjudging relative speeds of two or more vehicles. Finding ways to combat these types of misperceptions, or to present the driver with accurate information about such conditions, is an important human factors issue. Other issues impacting human perception include driver vigilance, learned inattention, experience, and age-related effects. For example, learned inattention refers to the situation in which drivers on rural roads may not get to the point of identifying a gap because they do not expect oncoming traffic in the first place.

Technological issues related to IDS

With the ultimate goal of improving human decision-making, Intersection Decision Support relies on a variety of technologies including surveillance, wireless communications, and real-time computation. The subsystems which perform these tasks must be seamlessly integrated to provide information to the driver in a timely manner.

- **Surveillance.** Tracking multiple vehicles traveling at varying speeds creates ever-changing configurations that are difficult for a human to interpret quickly. IDS will build on work already underway related to tracking vehicles. Radar, GPS, and digital map systems developed in the course of the University of Minnesota's Intelligent Vehicles research will play a role in the IDS system.

- **Computation.** Tracking algorithms that have already been developed will be leveraged and modified to track and predict vehicle trajectories in real time as vehicles approach the intersection. The ability to monitor and predict vehicle movements near rural intersections will be developed at an instrumented rural intersection.

- **Technology deployment.** It is misleading to suggest that deployment of some of the discussed technology may be less expensive than traffic signals. However, our intent is to develop a cost effective system that does not impede high speed traffic on what is likely a corridor for commercial traffic, and does not increase the occurrence of rear end

[3] Unfamiliar surroundings can lead to misperceptions, but this is often the result of divided attention. Complex or unfamiliar environments can distract the driver from performing the primary task of proper gap identification.

crashes typical of signalized intersections on high speed rural roads. We see the technologies and human interface and display systems developed as part of this project to be deployable shortly after a suitable field operational test.

The IDS development process

The following represents a summary of the scientific and technical directions planned for the IDS effort. Further information, and a more detailed workplan and budget for each state's contribution is available upon request. by contacting Daryl Taavola, ITS Program Manager at 651-282-2115, or by email at daryl.taavola@dot.state.mn.us. Questions about the pooled fund process can be addressed by David Johnson, MnDOT Research Director at 651-282-2270 or by email at dave.johnson@dot.state.mn.us

- **Resource Allocation**. Early in the process, relevant intersection crash data will be studied to determine which rural crash configurations and intersection types are associated with high frequency and severity of crashes. Further analysis of these crash configurations will be performed to determine the requirements for a system designed to avoid or mitigate the crash hazard. This process will encompass vehicle response, human response, and the capabilities of computing and surveillance systems.

Based on these requirements, and on the findings of ongoing research on relevant technologies and human factors, intersection crash configurations will be classified and assigned priorities for study. The goal of prioritization is to direct the effort where it will have the greatest impact on the improved safety and mobility of the driving public. Our goal is a deployable system which will offer tangible benefits to users of the transportation system.

- **Countermeasure Selection**. When a set of intersections for which IDS technologies and techniques are well suited has been identified, and a focused understanding of relevant human factors has been achieved, the next challenge is to determine the best countermeasure(s) from a family of possibilities. A benefit:cost methodology will be used to determine system trade-off issues such as the monetary cost of technology, the need to keep the commercial vehicle traffic moving, the requirements for installation and maintenance, and acceptance by drivers, to name a few. We wish to develop an array of solutions and to provide guidance as to which apply under what circumstances.

- **Enabling Research**. The innovative nature of Intersection Decision Support compared to existing intersection control strategies mandates a major research effort into component technologies and human factors. Issues involving the technological needs of the program include surveillance systems (vision, radar, GPS, etc.) and tracking systems (i.e., given the vehicle speed, position, and acceleration, can the gap length and its location be determined at a given confidence level), will be investigated. From the human side, research is needed to determine what data is required by the human so that decisions can be made intuitively and actions executed so that the collision is avoided. Complementing the study of what data is needed is an investigation into the determination of how best to present that information to a driver, while at the same time avoiding the introduction of new legal liability problems for the jurisdiction.

- **System Design and Testing**. The comprehensive design task includes consideration for the infrastructure, power, communication, sensing, computational, and human interface subsystems. Testing will include bench testing of subsystems, system testing in virtual reality driving simulators, and field testing at an actual intersection site.

Selected References:

[Carter, 1999] Arthur Carter, "Intersection Collision Avoidance Using ITS Countermeasures," presentation to TRB Task Force A3A35, NHTSA (under contract DTNH22-93-C-07024).

[Smith and Najm, 2001] David L. Smith and Wassim G. Najm, "Analysis of Crossing Path Crashes for Intelligent Vehicle Applications," Proceedings of the 8th World Congress on Intelligent Transport Systems, Sydney, Australia, October 2001.

[Najm, Koopman and Smith, 2001] Wassim G. Najm, Jonathan A. Koopmann and David L. Smith, "Analysis of Crossing Path Crash Countermeasure Systems," Paper #378, Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands, June 2001.

[Neuman, Pfeffer et al., 2003] Timothy R. Neuman, Ronald Pfefer, Kevin L. Slack, Kelly Kennedy Hardy, Douglas W. Harwood, Ingrid B. Potts, Darren J. Torbic, Emilia R. Kohlman Rabbani, "Guidnace for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions,' NCHRP Report 500, TRB Washington DC, 2003.

Advisory Committee

Bernie Arseneau, the State Traffic Engineer for the Minnesota Department of Transportation will chair the committee. Other members will be drawn from state departments of transportation that participate in the pooled fund.

The Study Team

Bernard J. Arseneau, State Traffic Engineer, Minnesota Dept. of Transportation
Bernard J. Arseneau is Minnesota DOT's State Traffic Engineer and the Director of the Office of Traffic, Security and Operations. Bernie joined Mn/DOT almost 20 years ago after receiving his Bachelor of Civil Engineering Degree from the University of Minnesota. During that time, he has held several positions within the department, including serving as the Director of Traffic Operations in charge of Mn/DOT Regional Transportation Management Center (RTMC), Area Maintenance Engineer for District 6-Rochester, Tort Claims & Traffic Standards Engineer, District Traffic Studies Engineer, and Legislative Liaison for the Department. Bernie is a registered Professional Engineer (P.E.) and a Professional Traffic Operations Engineer (P.T.O.E.).

Daryl J. Taavola, IDS Program Manager, Minnesota Dept. of Transportation
Daryl Taavola is ITS Program Director with the Minnesota DOT. He has more than 16 years experience in the area of ITS, advanced transportation management systems, and signal systems. Prior to joining Mn/DOT in 1992, Daryl was employed at URS Corporation/BRW, Inc. where he spent 7 years managing several ITS projects within the Midwest. Daryl also worked 9 years in the Los Angeles, CA area including serving as the manager of the Traffic Management Center (TMC) in the City of Pasadena and as a traffic signal design/operations engineer for Los Angeles County. Daryl received a B.S. in Civil Engineering from Michigan Tech University and is a registered professional Civil Engineer and certified Professional Traffic Operations Engineer.

Max Donath, Principal Investigator, University of Minnesota
Professor Max Donath is the Director of the Intelligent Transportation Systems Institute (***www.its.umn.edu***), the federally designated University Transportation Center at the University of Minnesota. The focus of the ITS Institute is on 'human centered technology to enhance safety and mobility'. Dr. Donath joined the faculty of the University of Minnesota after receiving his Ph.D. from MIT in 1978. During the last twenty five years, he has led research efforts in sensing and control systems as applied to assisting the physically disabled, robotics, and transportation. His most recent efforts have been

directed toward the application of sensors and control systems to improve the safety of vehicles used on the road.

Howard Preston – Traffic Engineering Consultant

Howard Preston is a Senior Transportation Engineer at CH2M Hill in St. Paul, Minnesota. He has a degree in Civil Engineering from Iowa State University and is a Registered Professional Engineer with more than 28 years of experience in the areas of transportation planning, traffic engineering and highway design. He has also prepared highway safety studies in Minnesota, Iowa and North Dakota and has published several traffic safety research reports. In addition to project related activities, he is a Fellow in the Institute of Transportation Engineers and a Past-president of North Central ITE, a member of the Minnesota Committee on Uniform Traffic Control Devices and an Adjunct Professor in the Civil Engineering Department at the University of Minnesota.

Craig R. Shankwitz – Site Manager, University of Minnesota

Craig Shankwitz received his Ph.D. in electrical engineering in 1992 in the area of control theory. After working at MTS systems as a control engineer responsible for the motion control of the National Advance Driving Simulator (NADS), he returned to the University to assume management of the University's Intelligent Vehicles Program at the ITS Institute. Dr. Shankwitz has been the project manager for the University of Minnesota Intelligent Vehicle Initiative (IVI) Specialty Vehicle Field Operational Test (see ***www.its.umn.edu/research/ivifieldtest/index.html***). For this project, he will perform a similar role as Site Manager for the University of Minnesota effort.

Nic Ward – Human Factors Lead, University of Minnesota

Nicholas Ward (M. Erg. S) obtained his Ph.D. in human factors psychology from Queen's University (Canada) with a dissertation on driver visual behavior and safety at rural railway crossings. Having spent almost 8 years conducting transportation and human factors research in Europe at Loughborough University and the University of Leeds, Dr. Ward is now the Director of the program for Human Factors Interdisciplinary Research in Simulation and Transportation (***www.humanfirst.umn.edu***) of the ITS Institute.

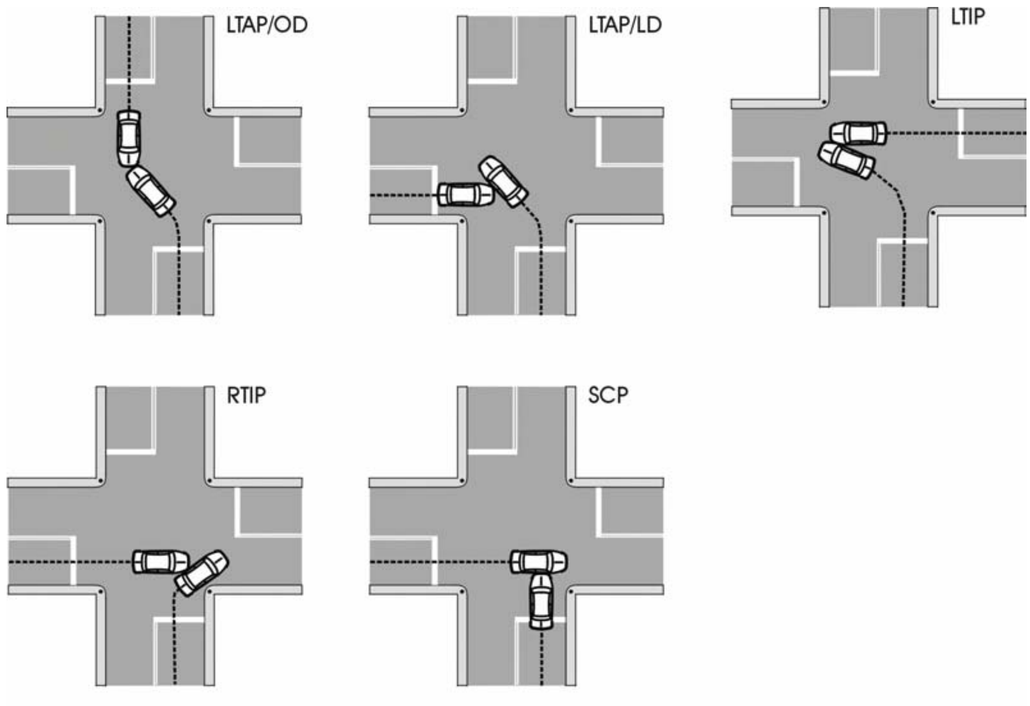

Figure 1. Crossing Path Pre-crash Scenarios

a. LTAP/OD: Left turn across path/opposite direction
b. LTAP/LD: Left turn across path/lateral direction
c. LTIP: Left turn into path
d. RTIP: Right turn into path
e. SCP: Straight crossing paths

Traffic Cntrl Device	Causal Factor	Crossing Path Pre-Crash Scenarios				
		LTAP/OD	LTAP/LD	LTIP	RTIP	SCP
Signal	Insuf. Gap	193,000			13,000	
	Signal Viol.	31,000	52,000	15,000	6,000	178,000
Stop Sign	Insuf. Gap	15,000	113,000	26,000	25,000	173,000
	Sign Viol.	1,000	12,000	7,000	3,000	62,000
No Controls	Insuf. Gap	92,000	25,000	10,000	11,000	35,000

Table 1. Crossing Path Crash Causal Factors at Intersections, Excluding DUI (1998 GES), from [Najm, Koopman and Smith, 2001]. There were virtually no crashes in the shaded cells.