

3.0 Intersection Safety

3.1 Introduction

A highway intersection is the junction of two or more public roads at equal grade. This is the only segment of our highway system where vehicles are in direct conflict due to opposing flows. Not surprisingly then, the intersection, whether or not it is under traffic signal control, can be a hazardous location as evidenced by various accident statistics reported below.

Intersection Safety Problem—Some Accident Statistics

The magnitude of the accident problem at intersections and some key characteristics are discussed below. The source of the information includes a 2001 paper by Harwood et al. entitled “Overview of Current Intersection Safety Conditions” and a compilation of accident statistics from the 2002 NASS-GES data base. The Harwood et al. analysis is drawn from two data bases: 1) three years (1998-2000) of the Fatality Analysis Reporting System (FARS), and 2) two states – Minnesota and California – within the FHWA’s Highway Safety Information System (HSIS). Some key findings are enumerated below:

- The magnitude of intersection accidents by severity is as follows:

	<u>Fatality</u>	<u>Injury</u>	<u>PDO</u>	<u>Total</u>
Signalized	1,971	444,866	822,760	1,269,597
Unsignalized	4,075	479,422	959,135	1,442,632

- About 22 percent of fatal accidents on all roads including freeways are intersection related. When not including freeways, the percentage increases to about 30 percent.
- 75 percent of the fatal intersection-related accidents were multiple-vehicle accidents. Angle/turning collisions accounted for the vast majority of the multiple-vehicle accidents.
- Signalized intersections consistently have higher percentages of multiple-vehicle accidents than stop-controlled accidents.
- 22 percent of the intersection-related fatal accidents involved alcohol compared to 39 percent for all fatal accidents.
- The percentage of fatal and serious injury accidents is generally higher at rural intersections reflecting the higher speeds and greater response time for emergency medical services.

These minimal statistics do not adequately characterize and describe the intersection safety problem and indeed, one of the key research needs that will be offered in this paper is to develop a comprehensive taxonomy of crashes at intersections.

Intersection Safety—A Priority

In recognition of the significant accident problem, achieving a higher level of intersection safety has become a priority of the public and private safety community as evidenced by the following:

- Intersection safety is one of the emphasis areas in the American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan.
- Intersection safety is also included in the Institute of Transportation Engineers' Safety Action Plan.
- Achieving a significant reduction in the number and severity of intersection crashes was identified by the Future Strategic Highway Safety Plan (F-SHRP) of the Transportation Research Board as a critical strategy in making a quantum leap in highway safety
- Intersection safety is recognized as one of four priority areas in FHWA'S Performance Plan.
- With the input of numerous public agencies and private organizations FHWA has established a national agenda for intersection safety.

Intersection Safety Research Needs—the Initial List

To achieve the goal of improving the level of safety at intersections, the need for research has been recognized by the safety community. While quite a bit is known about how to design and operate an intersection to maximize its capacity to handle traffic demands, the knowledge base for optimum safety is not as robust. The need for research to fill the gaps in safety knowledge was the focus of the Research and Technology Partnership—a group of public and private safety specialists—that conducted its first Safety Research Agenda Planning conference on September 17 and 18 in Irvine, CA. The participants at that conference identified four fundamental safety issues related to intersections that needed to be addressed, namely:

1. Effectiveness of stop-sign vs. signalized traffic control
2. Effectiveness of actuated vs. semi-actuated vs. fixed-time signalization
3. Relationship between signal-timing decisions and safety
4. Safety effects associated with traffic flow characteristics.

Additionally, the following specific research topics were identified:

1. Safety effects of cross-sectional elements at intersection
2. Safety performance of roundabouts
3. Analytical tools/models for traffic engineers and planners to consider the safety consequences of intersection safety and design
4. Safety effects of transitional elements moving from corridors to intersection approaches
5. How to accommodate various users (pedestrians, bicycles, trucks, etc.) for different scenarios
6. Safety effects of traffic-calming devices/perceptual measures
7. How does the culture of road user behavior evolve and how can it be influenced
8. Relationship of Intersection Sight Distance to safety
9. Analytical tools to identify which intersections to provide selective enforcement.

Objective of Paper

The purpose of this paper is to review the research needs identified from the Irvine Conference in light of: 1) intersection research needs identified elsewhere, 2) what is already known about the various topics, and 3) what research on a specific topic that is already being conducted. From this review, the more critical research needs are to be identified with an assessment of the likelihood of success and payoff potential. Summary research statements are prepared for the most critical needs; these include a problem statement, suggested approach, and estimated project duration and cost.

3.2 Potential Research Needs

While the list of research needs from the Irvine conference by itself covers a wide spectrum of issues for intersection safety, the search for research needs for this effort was broadened by a limited review of key literature and contacts with key persons involved in this topic.

Specifically, the following sources were reviewed:

- Safety Research Agenda Planning Conference, Summary and Proceedings—September 17-18, 2002, Irvine, CA.
- Mid-Atlantic Intersection Safety Workshop—June 18-19, 2003, Linthicum, MD
- Intersection Safety Workshop—November 14-16, 2001, Milwaukee, WI and the resulting “National Agenda for Intersection Safety” (FHWA Publication FHWA-SA-02-007.
- “Detailed Planning for Research on Making a Significant Improvement in Highway Safety, Study 2—Safety” F-SHRP Web Document 2 (NCHRP Project 20-58(2), September 2003.
- NCHRP Report 500, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions, Transportation Research Board, 2003.
- NCHRP Report 500, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume?: A Guide for Addressing Signalized Intersection Collisions. (draft)
- Signalized Intersection Safety in Europe, FHWA Report FHWA-PL-03-020, October 2003.
- “Task D, High-Volume Signalized Intersection Research Needs,” Draft Report under FHWA Contract by K. Courage and L. Rodegerdts, Jan. 2, 2004.

In addition, contacts were made with the following groups known to have interests and experience in highway safety:

- AAA Foundation for Safety—who were identifying research projects
- AAA Club, Michigan—who has a comprehensive intersection improvement program for cities in Michigan
- State Farm Insurance Company—who sponsors intersection safety improvements projects.
- Dr. John Mason, Pennsylvania State University—who participated in the above mentioned conference in Irvine, CA.

- Dr. Forrest Council—who has identified research needs to support the Highway Safety Information System (HSIS) program and chaired a subcommittee that developed a list of ranked safety countermeasures for the F-SHARP safety plan.

From these sources, a list of research statements/topics was compiled. The resulting list was lengthy, covered a wide spectrum of types of needs, and included redundant and overlapping topics. The list was streamlined by categorizing the research needs and collapsing similar topics. The resulting list is shown in Appendix A. In as much as practical and reasonable, the individual research statements are as proposed by the sources noted above.

The long list of research needs in Appendix A range from very specific issues, e.g. the safety effect of late-night flash mode, to very broad issues that encompass many aspects, e.g. the first need of a comprehensive and systematic analysis of intersection accidents. Some are simply too broad or vague in scope, e.g. relationship of cross-sectional elements to safety and need more focus. Some are a specific item within a broader issue; for example, establishing the effectiveness of rumble strips on intersection approaches is one of several statements that could be included under “determining the effectiveness of various countermeasures, especially those related to red light running” since it is one of the engineering countermeasures for red light running.

Research has already been performed on most if not all of these issues. However, given that the safety community has identified these as researchable topics, indicates that the research to date has not fully or satisfactorily resolved the issue. Also, it is known that some of these topics are being addressed in current on-going research or related projects.

With the considerations noted above a final list of what is considered the more critical research needs are presented in Table 3.1. In reviewing the list, perhaps conspicuous by their absence are needs focused on pedestrians and bicyclists, motorcycles, and large trucks—key users of the intersection. This is so because there already is a significant research and development program for these users and it is assumed that they would be considered in the conduct of any specific research project.

This list of 14 research needs can be further reduced because for some of them there is either an on-going or planned research effort. There is an on-going research effort that is examining the safety effects of roundabouts to include pedestrians. Also, an NCHRP project will commence soon that specifically deals with blind and handicapped pedestrians crossing at roundabouts and channelization lanes at intersections. Under NCHRP, there is a project that deals specifically with high-speed intersections and should address the need expressed by number 10. Also, within the New Technology Applications category, there is a research program within FHWA that is identifying how technology, either infrastructure and/or vehicle-based, can be applied to promote intersection safety. Finally, the two research needs listed under Safety Programs are already being addressed through the development of the Highway Safety Manual, the Integrated Safety Management Process, and Safety Conscious Planning.

Reference is also made to the F-SHRP research plan for intersection safety. As documented in “Detailed Planning for Research on Making a Significant Improvement in Highway Safety,

Study 2—Safety” (Campbell et al., Sept 2003), a multi-year research program was developed with the objective of determining the interaction of driver behavior with intersection design and operation in the risk of intersection collisions. All together, 14 projects were identified with the first five designed to develop the research tools and methods that would be used in the seven subsequent studies that would examine the multiple factors related to the risk of collisions and casualties for intersection safety issues. The final two projects deal specifically to countermeasure evaluations. The 14 projects are identified by title in Appendix B.

Finally, reference is also made to the research needs for high-volume signalized intersections identified by K. Courage and L. Rodegerdts. They identified numerous knowledge gaps for intersection safety (and operations as well). From that base, they developed five research project statements, all of which have safety impact as the primary or secondary issue to be addressed. The five projects are also listed in Appendix C.

With consideration to on-going and already programmed research, Table 3.2 provides a final list of what is viewed by these authors as critical research needs. The table lists eight projects by category, and notes the type of research, the likelihood of success from low (1) to high (5), the duration, and estimated cost. Preliminary project statements for each follow.

Table 3.1. Priority Research Needs to Promote Intersection Safety by Category

ACCIDENT CAUSATION

Comprehensive and systematic analysis of accidents at intersection to determine magnitude, characteristics, and causation factors that would identify priority problems and potential countermeasures.

Establish the root causes of intersection accidents attributable to driver error. Why do drivers take risks at intersections, such as running red lights or stop signs or turning left in front of on-coming traffic? Special consideration given to older drivers who are purported to be over-represented in intersection crashes.

RELATIONSHIP OF TRAFFIC AND OPERATIONAL FEATURES TO SAFETY

Safety impacts of no control vs. yield control vs. stop sign control vs. signal control, which would involve determining the relationship of traffic volume to accident occurrence.

Effects of protected/permissive left-turn signal phasing on safety.

RELATIONSHIP OF TRAFFIC CONTROL DEVICES TO SAFETY

Safety effects of alternative traffic signal layouts.

RELATIONSHIP OF DESIGN FEATURES TO SAFETY

Relationship of intersection sight distance to safety.

Safety performance of roundabouts and especially regarding pedestrians.

Innovative intersection designs (geometric or traffic control devices) in areas (highly urbanized) where right-of-way is limited (where desirable design standards can not be used.).

EFFECTIVENESS OF COUNTERMEASURES

Establish the effectiveness of various engineering countermeasures in reducing accidents.

NEW TECHNOLOGY APPLICATIONS

Identify and evaluate technologies to reduce accidents at high speed, rural intersections.

Develop and evaluate an automated all-red traffic signal extension system.

Develop and evaluate infrastructure-based technology to advise motorists of safe or unsafe maneuvers, such as left turn in front of opposing traffic.

SAFETY PROGRAMS

Develop strategies to identify potentially hazardous intersections, rather than wait on occurrence.

Analytical tools/models for traffic engineers and planners to consider the safety consequences of intersection safety and design.

Table 3.2. Suggested List of Critical Research Needs

Category	Project Title	Type of Research	Likelihood of success (1-5 scale)	Duration (months)	Cost (millions)
Accident Causation	IS 1a: Magnitude, Characteristic, & Causation of Intersection Accidents	Advanced	Moderate to High, 4	36	\$1.5 - 2M
	IS 1b: Establish Root Causes of Driver Error	Advanced	Moderate 3	24	\$0.5 – 0.75 M
Relationship of Safety to:					
a. Traffic & Operational Features	IS 2a-1: Safety Impacts of Alternative Intersection Controls	Advanced	Moderate 3	36 - 60	\$1.0 – 1.5 M
	IS 2a-2: Safety Effects of Alternative Left Turn Phasing	Applied	Moderate 3	24	\$0.3 M
b. Traffic Control Devices	IS 2b: Safety effects of alternative signal layouts	Applied	Moderate to High, 3	36	\$0.3 M
c. Design Features	IS 2c: Intersection Sight Distance	Advanced	Low to Moderate, 2	24 - 36	\$0.5 M
Effectiveness of Counter-measures	IS 3: Effectiveness of various countermeasures for reducing accidents	Applied	Moderate to High, 4	84 for all phases	\$2.0 M
Advanced Technology	IS 4: Effectiveness of & Driver Response to Automatic All-red Signal Extension System	Applied	High, 5	6	\$0.05 - \$0.1 M

Research suggestions from R&T Partnership Steering Committee

The following items seem worthy of development as full research statements in the plan. Most, but not all, of these items are addressed in Appendix A of the white papers:

- Safety effects of alternative signal control strategies (i.e., are there safety differences or is this just an issue of operational efficiency?)
- Safety effects of adaptive signal timing (i.e., are there safety benefits or is this just an issue of operational efficiency?)

- Safety effects of alternative signal timing strategies (i.e., given that the cycle length determines the number of occasions of “turbulence/hour), study the safety effects of inappropriate/inefficient cycle lengths)
- Safety effects of late-night flash mode (make sure that sight distance is considered in this study)
- Safety effects of offset T intersections vs. four-leg intersections (are two T-intersections safer than one four-leg intersection, or does this depend on the magnitude of the minor-road through volume)
- Are dynamic advance warning signs effective on intersection approaches? Are they effective on the major road when tied to the start of the red signal phase on a signalized intersection approach? Are they effective when tied to the speed of the vehicle for which the sign is activated? Are they effective when tied to the presence of a potentially conflicting vehicle on the minor-road approach when an approaching major-road vehicle is detected?
- Safety effectiveness of left-turn acceleration lanes at divided highway intersections
- Safety effectiveness of right-turn acceleration lanes
- Safety effectiveness of offset right-turn lanes
- Safety effectiveness of innovative intersection designs
- Safety effectiveness of automated real-time systems to inform drivers of the suitability of available gaps for making turning and crossing maneuvers (evaluate existing installation in Missouri and Maine)
- Safety effectiveness of dilemma-zone detection at high-speed intersections
- Intersection size and density - All research finds that the frequency of crashes depends on (Traffic Flow)^β with β usually about 0.5. This means that if one intersection with an inflow of 10,000 vpd replaces two intersections with an inflow of 5,000 vpd, we will save about 30% of the intersection accidents. However, fewer intersections mean somewhat longer link travel. Nevertheless, since we are building and re-building our environment all the time, this potential for accident reduction ought to be examined and translated into guidance to planners and engineers

Response from White Paper authors

If any of the above research topics are not included in the full list in Appendix A, we will add them in the edited version. We are not in agreement that they all need a full research statement. Some are being evaluated in current or already planned research, namely:

- Safety effectiveness of innovative intersection designs
- Safety effectiveness of automated real-time systems to inform drivers of the suitability of available gaps...
- Safety effectiveness of automated real-time systems...

Some could be included within one research statement prepared here, namely:

- Intersection size and density...--Statement IS 2a-1—while cast as intersection control, the variables of size, type, and volume should be considered in the design. The issue of density, i.e. frequency of intersections per distance, is a matter of accessibility and

roadway network design and safety, like or not, is not explicitly considered. However, some of the guidelines that have evolved from Access Management should apply.

Some we considered but passed on, namely:

- Safety effects of alternative signal control strategies—we feel that it is predominantly an operational/efficiency issue. If you improve operations, then you improve safety.
- Safety effects of adaptive signal timing—same comment from above applies.
- Safety effects of alternative signal timing strategies—same comment from above applies.

For all others, they did not make our shortlist since we were limited in scope/budget as to the number of research statements to prepare, those did not make our short list.

IS 1a. Accident Causation: Determine the Magnitude, Characteristics, and Causation and Contributing Factors of Crashes at Intersections

Comment from R&T Partnership Steering Committee

The authors assert that in order to develop countermeasures to reduce the number and severity of intersection accidents (efficiently), one has to have a good understanding of how accident frequency and severity depend on variables such as traffic volume, design and operational features, and driver and vehicles characteristics. It would then make sense to see the purpose of a research program as the development of such an understanding. However, this is not what their problem statement is about. Their problem statement is about describing how many crashes of what kind occur at intersections and what are the factors that cause and contribute to their occurrence. Description of magnitude does not amount to understanding. Determination of factors and causes is not the same as (and falls very short of) knowing how frequency and severity depend on a factor or a variable.

Response from White Paper authors

We agree with the reviewer's comment. This project statement emerged from this author's inability to find a single or even a few documents taken together that adequately described and quantified the crash problem at intersections (which admittedly does not by itself identify causation and contributing factors). We believe such an investigation would be the first step in a comprehensive research study that would subsequently explore the caused relationship of crashes and crash severity to the various design, operational, driver, vehicle and environmental factors.

We did not intend that this or the other remaining project statements are "final" statements—sufficiently and adequately developed for release for a proposal—but rather a preliminary statement of what is needed and how one might approach the problem. We would expect that a group of experts would develop a more complete research statement. Hence, for the purposes of this initial "white paper," we have not made any changes to this research statement, feeling that it captures the first step of a multi-step program that ultimately will result in better understanding.

Background

Intersections account for a significant percentage of all crashes and resulting fatalities, injuries and property damage. A complete and comprehensive understanding of how many occur as a function of the many influencing variables related to traffic volume, design and operational features, and driver and vehicle characteristics is paramount to developing countermeasures to reduce their occurrence. While numerous accident studies have been undertaken in the past, they have been piecemeal in that they have focused on elements of the problem or have not been conclusive because of the lack of desirable databases of crashes and the influencing variables. Improvements in agency databases are at a point where this deficiency can be overcome and when coupled with supplemental data collection can provide the needed data.

Problem Statement

Conduct a comprehensive and systematic analysis of crashes at intersections to determine their magnitude and characteristics and the factors that cause and contribute to their occurrence. All types of intersections--as defined by its control--on all classes of roadways under state and local control should be included. Databases from multiple states representing variation in climate and terrain should be included.

Method / Approach

The methods and approach should be dictated by a thorough data collection and analysis plan developed to address the many issues and facets of the problem. It is expected that several databases will be utilized to include the FARS and GES databases from NHTSA's NASS, FHWA's Highway Safety Information System, and special databases developed from a large sample of crash investigations.

Project Duration

A project of this scope and complexity will likely take at least 3 years, with up to a year for planning and site selection, a year for special data collection, and a year for analyses and reports.

Project Cost

Given the project duration and the likely need for substantial field data collection and crash investigation, the cost of the project is estimated at \$1.5 to \$2.0 million.

Payoff Potential

If this project can be successfully completed, it will have significant payoff, not so much in a tangible measure to directly reduce crashes, but as a sound foundation for identifying the nature of the safety problem and measures that would be effective in reducing crashes and their severity.

IS 1b. Accident Causation: Establish the root causes of crashes attributable to driver error.

Comment from R&T Partnership Steering Committee

There's no consensus agreement on the value of this project among the reviewers. There are many difficulties in conducting this research (e.g., what method can be used to "get into the driver's head?"). Also, reviewers are not totally convinced that one has to know the reason why,

as long as one can develop a treatment that affects the behavior (e.g., whether a driver runs a signal due to “frustration at home” vs. “risk taking” may not matter as long as a red-light-camera can affect the behavior). So there needs to be some preliminary thinking done about understanding why root causes are important from a behavior-change point of view. What can be done about root causes? If willful risk taking were found to be a significant proportion of root causes, then, before countermeasures are contemplated, one will have to find out why people take risks knowingly. Thus, one will have to search for the root causes of the root causes. Perhaps it was congestion, perhaps the pressures of urban living, perhaps inherent personality traits. (On this question too there is no shortage of research findings). In none of these cases (congestion, urban living,...) it is clear what countermeasure applies; perhaps no countermeasure exists. However, if it is thought that enforcement might work on willful risks, then the question will be how well will it be likely to alter willful risk taking. This last question is one about the expected effectiveness of a countermeasure. Answering the question of expected countermeasure effectiveness is an inherent part of developing any countermeasure. Unfortunately, this is not a part of the proposed causation study.

Response from White Paper authors

This research statement emerged from the emphasis placed on it at the Irvine Conference. We do recognize and appreciate the issues and concerns raised by the reviewers. It will not be easy to identify what the “root” causes are and how far down the “root” does one try to go! The resolution of this issue should be left to the researchers. As to whether or not it is necessary to know the reason why drivers behave the way they do, we wish to offer the following comments. It is arguable that it is useful to know that driving violations, e.g. running red lights, are attributable to “willful” risk. In other words, possible responses why a driver takes a willful risk (i.e., “hey, I knew it was red, but didn’t want to stop”) may include a) I was late, b) it’s just my personality, or c) I just lost my job and was mad that day. Likewise, it is desirable to ascertain if the driver takes an unintended risk, such as “I didn’t realize it was red”, “I was daydreaming”, or “I didn’t see the red until it was too late to stop”. If we can get a handle on this issue, then we can better devise countermeasures, be they enforcement, education or engineering. This is clearly preferred, rather than implementing a countermeasure and subsequently determining if it positively affects the behavior.

Again as stated above, we believe the essence of the researchable issue ought to remain and the specific objectives, procedures and methods should be determined by the group that finalizes the project statement and eventually selects the researchers.

Background

Driver error is by far the most often-cited crash causation factor cited by the police. There are likely other factors related to the highway, e.g. limited sight distance; the vehicle, e.g. brakes in poor condition; and the environment, e.g. slippery conditions, that may have contributed to the accident, but the driver is typically cited for not being able to control his/her vehicle in spite of these conditions. There are many other crashes where there is no apparent contributing deficiency, and for whatever reason the driver collides with another vehicle or pedestrian in the intersection. In these cases are drivers knowingly taking risks, do they misidentify risks, or are they distracted? The root causes of intersection accidents need to be established, so that the most

appropriate type of countermeasure in terms of education, enforcement or engineering can be developed.

Problem Statement

This project will examine and identify the reasons why drivers make errors at intersections that result in crashes. It will establish why drivers knowingly or unknowingly take risks in negotiating intersections. For example, why do drivers run red lights or stop signs or turn left in front of on-coming traffic? Special consideration should be given to older drivers who are purported to be over-represented in intersection crashes.

Method / Approach

This project may need to take alternative approaches. One approach will be to conduct in-depth investigations, to include interviewing drivers, of a sufficient sample of crashes. Another approach would be to conduct laboratory and/or field studies to observe driver behavior under various conditions. The laboratory study may involve a driver simulator. While this project has a more specific focus than the first statement, it could be included within the approach of the first statement.

Project Duration

This project will require at least two years depending upon the types of studies conducted in the laboratory or field.

Project Cost

It is estimated that this project will cost from \$0.5 to \$.75 million depending upon the sample size of the crash investigations and the types of laboratory and field studies conducted.

Payoff Potential

Having a thorough understanding of why drivers take risks and/or make errors in negotiating intersections will have a high payoff for determining what type of countermeasures may be appropriate.

IS 2a-1. Traffic & Operational Features: Safety impacts of alternative intersection controls

Comment from R&T Partnership Steering Committee

This is worthwhile study. The review of current literature to determine what is unknown is important. Two controls seem to be missing in the discussion within the white paper: all-way stop control and roundabout. The results of the recently completed NCHRP 17-16 study “Accident Warrant for Traffic Signals” should be examined.

Response from White Paper authors

We concur that all-way stop and roundabouts should be included and have made changes to reflect that in our revised version of this white paper.

Background

Typically, right-of-way and vehicular traffic flow is controlled by either one of four ways: 1) no specific traffic control device and right-of-way is established by vehicle code, 2) yield sign, 3) stop sign including all-way stop, and 4) traffic signal. Lately, roundabouts have become a viable intersection control strategy. In general, the need for each type is based upon traffic volumes and the most efficient control for traffic operations. While safety concerns can dictate which type of control is used, there is no well-defined safety relationship for the various types of control. Intuitively, as traffic volumes increase there are more conflict opportunities that can result in vehicle accidents for each level of control. After a certain level of accidents, a more restrictive control, e.g. stop sign to signal control, may reduce total accidents or accident severity but then will eventually increase with increasing volume. The threshold accident values under the different controls have not been established.

Problem Statement

The objective of this research is to determine how safety, in terms of vehicular accidents and severity, are affected by the type of intersection control. All types of control should be considered to include no control, yield sign, stop sign, signal control, and roundabouts. Since traffic volume levels will likely be an influencing factor, all levels should be considered in rural, suburban, and urban settings.

Method / Approach

This project will require an analysis of crash data for a large sample of intersections with the all four controls. At least 3 years of crash and traffic volume data will be needed; and if not available from data files historically, it will need to be collected over that period in the future. Standard statistical methods need to be employed to develop relationships and predictive models. A desirable product would be to develop threshold values or plots of crash statistics to traffic volumes for different control strategies. The design of this project could be integrated with problem statement #1.

Project Duration

This project will take at least 3 years and up to 5 years if historical data can not be obtained.

Project Cost

The project cost is estimated at \$1 to \$1.5 million to insure an adequate sample size and robust data.

Payoff Potential

Successful completion of this project would yield more reliable values for determining the appropriate control strategy for intersections for safety.

IS 2a-2. Traffic & Operational Features: Determine the relationship between left-turn traffic signal phasing and safety.

Comment from R&T Partnership Steering Committee

Research on this topic should be explored.

Response from White Paper authors

It appears that a response is not necessary as there is agreement.

Background

Most traffic engineers perceive that protected only left-turn phasing is generally safer compared to protected-permitted left turn phasing. They also perceive that protected-permitted phasing generally has a higher capacity than protected only phasing. Thus, they recognize phasing decisions as a trade-off between safety and capacity. Within many agencies, traffic engineers believe that protected-permitted phasing is “safe enough” and acceptable for use if intersection sight distance for a driver turning left from the left turn lane is adequate and if there are a limited number of opposing lanes. While many traffic engineers spend substantial amounts of time performing level of service calculations to evaluate an intersection, they rarely if ever perform any analysis to estimate the impacts on safety resulting from their decisions about signal phasing.

Problem Statement

The primary objectives of this study would be to quantify the differences in crash experience between protected-only left turn signal phasing and protected-permitted left turn signal phasing in terms of intersection geometry, posted approach speed limits, traffic volumes, and other factors related to signal control. The secondary objectives would be to quantify the safety effects for other intersection control scenarios related to signal phasing/traffic signal control practices, such as:

- Protected-permitted and protected left turn phasing on opposite approaches
- Lead/lag left turn phasing
- Leading green for one approach without separate left turn lanes
- High type T-intersections with continuous through movement on one approach.

Method / Approach

The proposed method for this study would feature two different approaches. The first would be to conduct before-after studies of intersections where left turn signal phasing has been changed. This would result in the development of crash modification functions for the selected signal phasing treatments. The second approach would be to compile data and conduct statistical analysis of a more varied range of intersections to establish relationships between crashes and signal phasing/traffic operation strategies.

Project Duration

This project could be completed within 24 months if the data were readily available. However, since there is a desire to also include knowledge gained from before and after studies, it is recommended that 36 months be established as the period of performance.

Project Cost

A project of this magnitude is estimated to cost \$300,000.

Payoff Potential

Reductions in left-turning crashes at signalized intersections would be the payoff.

IS 2b. Traffic Control Devices: Determine the effect of different traffic signal layouts on accidents at intersections.

Comment from R&T Partnership Steering Committee

Several reviewers question the relative size of the problem and feasibility of doing the research. The “most critical” designs in terms of possible confusion should be given consideration but again, there’s a question about the relative size of the issue.

Response from White Paper authors

We wonder how the reviewers know the size of the problem since we did not uncover directly relevant information that addresses the issue. Hopefully, the question of magnitude of the problem would be answered in part by the first project statement. This topic was raised by others and our own experiences indicate that there is still no nationally accepted consensus on this. Therefore, the topic is still in need of research. We couldn’t find anything that said that such and such layout for a geometric design is preferred. Hopefully such guidance would result from this research. The end result is that the research could lead to more consistency in signal layouts and design among the states and local agencies. The authors are not convinced that this topic should be deleted.

Background

While the *Manual of Uniform Traffic Control Devices* contains explicit guidance on traffic signal heads, displays and indications, there is still a wide range of acceptable practices for traffic signal layouts. Consequently, there is a wide variety of configurations involving the types and locations of traffic signal heads that are used throughout the United States. Several human factors studies have suggested that older drivers may be confused by traffic signal displays. Other studies have raised the issue that the complexity and inconsistency of traffic signal displays may contribute to intersection crashes. Moreover, some traffic signal configurations may contribute to red light running. It is recognized that some research studies have investigated the effects of traffic signal displays, although many of them may no longer be applicable since the equipment has changed dramatically (e.g., greater use of LED displays, selected view technologies, changes in mounting hardware, etc.). In addition, a greater range of non-traditional signal configurations and traffic operations practices has been implemented subsequent to those older research studies.

Problem Statement

The primary objectives of this research would to determine the crash experience at intersections for a full and complete range of traffic signal layouts; to identify those layouts that experience high crash experience; and to develop improved guidelines on the optimal traffic signal layouts for a range of intersection conditions.

Method / Approach

One approach to address this topic would be to gather data on reported crashes, traffic volumes, intersection geometric conditions and traffic control equipment at a large number of intersections. Then, through statistical analysis, accident relationships could be established as a function of traffic volumes and geometric conditions for a range of different traffic signal layouts. To ensure that the appropriate types of traffic signal displays are investigated, it is suggested that a directed survey of practice be conducted of states, counties, cities and towns as part of this project.

Project Duration

To accommodate the data collection and analysis effort, it is estimated that three years would be needed for this study.

Project Cost

A project of this magnitude is estimated to cost \$300,000.

Payoff Potential

If successful this project could yield a more consistent design of traffic signals, thereby reducing possible confusion of the driving public and improved adherence.

IS 2c. Design Features: Establish the relationship of intersection sight distance to occurrence of accidents.

Comment from R&T Partnership Steering Committee

Reviewers feel this is an important research topic and feasible if targeted to two-way stop controlled intersections. Also, some reviewers suggest more thought needed on details of problem (e.g., sight triangle vs. nearby curves and grades) and on research method to be used.

Response from White Paper authors

It was intended that the two-way stop controlled intersection would be the primary intersection type to study, and that sight distance would be one of several factors to be investigated although it may not have been explicitly stated in the earlier draft white paper. Sight distance (corner sight triangle) is critical for Yield and no-control intersections, but these intersections have low volumes and/or low speeds and would be more difficult to study. We will address the “more thought” comment in the edited version.

Background

Adequate sight distance for the driver to see objects in the roadway and various traffic control devices is a basic design element for all road types and locations. It is important for intersections, where motorist must be able to see the intersection as they approach and then be able to see other motorist who may be in conflict as they proceed into the intersection if turning left or right or proceeding straight through. It is especially critical for non-signalized intersections where right-of-way is not controlled by a signal and motorist must make decisions about the presence of gaps in the traffic stream to allow safe maneuvers through the intersection.

Problem Statement

This project will examine the relationship of intersection sight distance to the occurrence of accidents. Sight distance to the intersection along the approaches as well as the corner sight triangles should be included with emphasis placed on higher speed roadways.

Method / Approach

The standard research method for developing a relationship of a design element to safety, i.e. accident occurrence, is to develop an accident predictive model based on the experiences of a large sample of locations with variations in the primary influencing variable—for this case intersection sight distances—while controlling or otherwise accounting for other variables to include traffic volume, speed, grade, etc. It is reasonable to hypothesize that as corner sight distance decreases from some threshold value, that accident occurrence will increase given certain set of conditions, e.g. volume level. This method may prove to be too difficult and costly to be practical. It will require measuring sight distance for each corner in both directions and then identifying accidents attributable to the conflicting vehicle scenarios. Traffic volumes at the turning movement level will be needed as well. Alternatively, and even as a supplement to the above approach, accident reconstruction and forensics of a smaller sample of crashes could be conducted. The purpose of this method would be to better establish if sight distance limitations had a causative or contributing effect to the accident.

Project Duration

The complexity of the research method will require a study period of 2 to 3 years. Adequate time is needed to develop a thorough research design, locate sites, obtain the necessary data, and conduct the various analyses.

Project Cost

It is estimated that this project will cost at least \$500,000.

Payoff Potential

A better understanding of the role that intersection sight distance plays in accident occurrence will help designers determine the safest design and allow traffic engineers to identify problematic intersection based on deficient sight distances.

IS 3. Effectiveness of Countermeasures: Determine the effectiveness of various countermeasures for reducing accidents at intersections.

Comment from R&T Partnership Steering Committee

All agree good evaluations are needed. Studies need to be prioritized, but not just by a practitioner survey. Priority should be based to a large extent on the size of the problem, expected effect, and feasibility of study.

Response from White Paper authors

This is a good point, and we have incorporated this topic into the revised version.

Background

Few definitive relationships have been established linking specific treatments implemented at intersections and the resulting crash experience. While all State transportation departments and many local agencies have highway safety improvement programs, practitioners still struggle with the selection of appropriate safety improvements at intersections. Without an adequate knowledge base, practitioners frequently make less than optimal decisions. They also cannot convince decision makers to expend additional resources for needed safety improvements. Moreover, they cannot accurately assess the impacts on safety of a wide variety of geometric and traffic control alternatives for intersection projects.

Problem Statement

The primary objectives of this study to develop improved and enhanced crash modification functions (e.g., accident reduction factors) for intersection treatments. Subject to funding and data availability, crash modification functions are desired for a extensive list of treatments likely to include LED signals, red light strobes for traffic signals, internally illuminated street name signs, highly reflective street name signs with large letters, offset left turn lanes, right turn acceleration lanes, bypass lanes on shoulders at T-intersections, rumble strips on approaches to intersections, supplemental stop signs mounted over the roadway, flashing beacons mounted on STOP sign structures, and others that would be identified through this project.

Method / Approach

The approach would feature three phases. Phase 1 would involve identifying the countermeasures and establishing a priority for conducting further evaluations. Priority could be based on the size of the problem—which could come from the first project statement, the expected effect, the feasibility of the necessary study, and input from practioners gleaned from a survey.. Phase 2 would focus on assembling and assessing the best available information on crash reduction factors in the literature and state practice. Phase 3 would to re-analyze base data and conducted new analyses to derive improved accident modification functions for selected countermeasures.

Project Duration

To properly conduct this study and investigate a broad range of countermeasures, it is recommended that the study be conducted in multiple phases. Phase 1 could be completed in 12 months. Phase 2 would require an addition 18 to 24 months. Phase 3 is estimated to take 5 years.

Project Cost

A project of this magnitude is estimated to cost \$2,000,000.

Payoff Potential

The payoff could be incremental reductions in crashes at improved intersection sites resulting from better decisions with respect to the selection of countermeasures at a local and state level.

IS 4. Advanced Technology: Determine Effectiveness of and Driver Response to an Automatic All-Red Signal Extension System

Comment from R&T Partnership Steering Committee

Some of the wording of the problem statement is confusing (E.g., 10% percent of red light crashes occur after the first second of the violator's red phase" Does this imply that 90% of red light crashes involve a violation during the first second of the red?) The data for this study can come from red light running cameras. Research on this topic should be coordinated with ITS research regarding systems that warn drivers who are about to violate a traffic signal or alert them to potential collisions with traffic signal violators.

Response from White Paper authors

We have addressed these comments in the revised version.

Background

Red light running is a major cause of intersection crashes. Yet, studies have shown that 90% of all red light running violations occur in the first second of the red signal indication, which may or may not be during the all-red interval, where no opportunity to collide with another vehicle exists. If the time for the all-red light could be extended for those motorist who are likely to "run the red light", which would provide an extra "grace" period, then the probability of a crash with side traffic entering the intersection could be reduced. Modification of current violation detection technology and algorithms (similar to those used in red light cameras) may be used to determine violators a few seconds prior to a light turning red. These few seconds of advanced warning can provide an automatic extension of the all red signal to prevent cross traffic from entering the intersection.

Problem Statement

Automatic extension of the all-red phase by a couple of seconds for violators detected early can catch motorists. A major drawback is that automatic red light extension can only be used for a couple of seconds after cross traffic is programmed to receive a green ball and cannot be used to prevent crashes due to mid-cycle red light violations. Examining exact violation times will show the effectiveness of automatic red light extension as a crash prevention method.

Method / Approach

A study of the effectiveness would involve two measures: violations and crashes. Violation frequencies could efficiently be determined at sites with red light camera systems or special video apparatus could be installed to collect this measure. Of concern is motorist adaption to red light extensions systems and the possibility of taking advantage of the extra time knowing that it is operating at a given intersection. Crash analysis using before/after with an appropriate control or reference group should be pursued to determine the crash changes.

Project Duration

If the measure of effectiveness was limited to violation changes, then this study could be completed within a year. Assuming that the evaluation should include crash analysis then, depending upon the analysis method employed, the project could take up to three years or more.

Project Cost

Expected costs depend upon the effectiveness measures used. For the violation measure of effectiveness, this project could likely be conducted for less than \$100,000. The crash analysis would increase the estimated cost by at least another \$100,000.

3.3 Summary

This paper has identified numerous research needs to address the gaps in knowledge of intersection safety. Starting from a long list of needs culled from various sources that individually have identified research needs, those that were felt to be the more critical and for which there is no known research project planned were identified and categorized. All of them are worthy of attention and successful conduct will offer solutions and strategies to achieve the goal of improving intersection safety when implemented. However, not all projects can be pursued at once, and perhaps nor should they be. The highest priority should be to develop a comprehensive research program that would identify the magnitude, characteristics and causation of accidents at intersections. A properly designed program will likely involve a series of specific projects that will answer two fundamental inter-related questions such as:

- What is the magnitude and characteristics of accidents at intersections?
- What part does the driver, vehicle, roadway, and the environment play individually and collectively in accident causation?

Once these two basic questions (and variations to them) are answered, then future research can address the specific factors that cause crashes at intersections and determine appropriate countermeasures or changes in design and operations of intersections.

3.4 Appendix A

FULL LIST OF INTERSECTION SAFETY RESEARCH NEEDS BY CATEGORY

ACCIDENT QUANTIFICATION, CHARACTERIZATION, AND CAUSATION

1. Comprehensive and systematic analysis of accidents at intersection to determine magnitude, characteristics, and causation factors that would identify priority problems and potential countermeasures.
2. Establish the root causes of intersection accidents attributable to driver error. For example, why do drivers expose themselves to crashes or what is the mental breakdown that e.g. allows a person to drive into the path of speeding truck; improve understanding of the underlying causes of driver distraction and error at intersections. Why do drivers take risks at intersections—why do drivers run red lights or stop signs or turn left in front of on-coming traffic. Special consideration given to older drivers who are purported to be over-represented in intersection crashes.
3. How does the culture of road user behavior evolve and how can it be influenced?
4. Does driver behavior (speeding, aggressive driving) affect the collision risk of intersection maneuvers?
5. Does information overload exist at intersections and does it contribute to accident causation?
6. What is the role of inattention in collision risk at intersections?
7. Does the relative risk of different intersection maneuvers vary with driver age and gender?
8. How does the pattern of conflicts and collision vary with traffic volume? Is there a safety relationship to intersection capacity as defined by level-of-service or volume-to-capacity ratio.
9. Why drivers sometimes confuse some two-way stops as all-way stops. Are there visual queues that lead them this? Are there visual queues that can be implemented to lessen confusion? What are the effective applications of using the “Cross-Traffic Does Not Stop” sign?

RELATIONSHIP OF TRAFFIC AND OPERATIONAL FEATURES TO SAFETY

1. Safety impacts of no control vs. yield control vs. stop sign control vs. signal control. Safety effects associated with traffic flow conditions; occurrence of accidents as a function of traffic volumes.
2. Safety impacts of alternative signal control strategies: a) fixed-time, semi-actuated, fully-actuated controllers and b) free vs. coordination. How does adaptive signal timing (e. g. SCATS, SCOOT, etc.) affect safety?
3. Safety impacts of alternative signal timing strategies: a) short vs. medium vs. long cycle lengths and b) inappropriate/inefficient signal timing effects on safety.
4. Safety effectiveness of dilemma elimination systems for intersections (i.e. extension of green for vehicles that enter dilemma zone).
5. Safety impact of clearance intervals for trucks at signalized intersections.

6. Safety effects of late-night flash mode
7. Effects of protected/permissive left-turn signal phasing. Effects of protected left-turn phasing at high-speed rural intersections.
8. Determine safety impacts and countermeasures of stopped or parked vehicles to include urban goods movement and vehicular parking. Transit issues such as bus stop location would be included as well.
9. Safety impact of right-turn-on-red on vehicular and pedestrian traffic.
10. Safety implications of bus signal priority systems.

RELATIONSHIP OF TRAFFIC CONTROL DEVICES TO SAFETY

1. (Dis)Benefits of different traffic signal layouts—a study that would lead to a standard or guideline for consistent traffic signal layout. Tie in with improving signal visibility. How would this reduce crashes?

RELATIONSHIP OF DESIGN FEATURES TO SAFETY

1. Cross-sectional elements at intersections to include lane width and median width.
2. How do turn lanes change the pattern of conflicts at an intersection?
3. Intersection sight distance.
4. Safety effects of transitional elements moving from corridors to intersection approaches.
5. Safety effectiveness of right-turn acceleration lanes.
6. Safety effectiveness of offset right-turn lanes.
7. Safety effectiveness of left-turn acceleration lanes at divided highway intersections.
8. Safety comparison of four-legged intersections vis-à-vis two T-intersections
9. Safety performance of roundabouts and especially regarding pedestrians.
10. Safety effects of alternative intersection types and especially innovative and non-standard designs such as jughandles, median U-turns, continuous flow intersections, etc.

EFFECTIVENESS OF COUNTERMEASURES

General

1. Control vehicle speed thru intersections using combination of practices such as speed tables, pavement markings, automated photo enforcement and changeable-message signs.

Traffic Control Devices

1. Flashing beacons, such as those mounted on Stop sign structures, or Stop Ahead signs, or with overhead intersection beacons; flashing red beacons activated by approaching cross-street through traffic; or flashing yellow warning beacons on the through road activated by side-street traffic.
2. Pedestrian Count-Down Signals
3. Roadside markers or pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers
4. Determine effectiveness of various countermeasures esp. those in “Engineering Countermeasures for Red Light Running”

5. Safety effects of different sized signal heads (8" vs. 12")
6. Safety effects of providing signal per approach lane
7. Safety effects of signal placement—overhead vs. nearside.
8. Red light strobe evaluation.
9. Larger regulatory and warning signs at intersections
10. Rumble strips on approaches
11. Supplemental stop signs mounted over the roadway
12. Supplemental messages on pavement such as STOP AHEAD
13. Benefits of using back lit and disappearing legend warning signs at intersections.
14. Comparison of internally illuminated and highly reflective large street name signs. Is one better than other and cost-effectiveness.
15. LED signals

Traffic Control Operations

1. Effects of closed-loop signal systems
2. Safety effect of detector placement and signal timing parameters for semi-actuated signals

Geometric changes

1. Longer left turn lanes
2. Offset left-turn lanes
3. Bypass lanes on shoulders at T-intersections
4. Left-turn acceleration lanes at divided highway intersections
5. Longer right turn lanes
6. Offset right turn lanes
7. Right turn acceleration lanes
8. Full width paved shoulders in intersection areas
9. Innovative intersection designs (geometric or traffic control devices) in areas (highly urbanized) where right-of-way is limited (where desirable design standards can not be used.) Indirect left-turn treatments to minimize conflicts at divided highway intersections

NEW TECHNOLOGY APPLICATIONS

1. Automated real-time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers.
2. How does transit signal priority affect intersection safety?
3. Enhance dilemma-zone detection at high-speed rural intersections using MOVA, LHOVRA, and similar technologies
4. Dynamic (actuated) clearance/all-red intervals.

ENFORCEMENT

1. Attitude of Law Enforcement Community towards highway safety
2. Analytical tools to identify which intersections to provide selective enforcement

3. Effectiveness (short and long term) of targeted enforcement to reduce stop sign and signal violations.

SAFETY PROGRAMS

1. Evaluation of Intersection Improvement Program, e.g. Michigan's AAA.
2. More timely process for implementing safety improvements.
3. Safety audit procedure
4. Develop strategies to identify potentially hazardous intersections, rather than wait on occurrence.
5. Analytical tools/models for traffic engineers and planners to consider the safety consequences of intersection safety and design; Safety as an explicit item in design.

PEDESTRIAN AND OTHER NON-VEHICLE USERS

1. Guidelines for improving pedestrian safety at signalized intersections using strategies such as PUFFIN and TOUCAN crossings, countdown indicators, and audible pedestrian signals.
2. Safety benefits of accessible/audible pedestrian signals.
3. What are the most cost-effective strategies and measures for accommodating handicapped?

3.5 Appendix B

Listing of titles of research projects related to Intersection Safety proposed for F-SHRP

Topic 2-1: Research Tools and Methods

1. Legal and Privacy Issues in Recruiting Volunteer Drivers and Vehicles for Field Studies of Driving Safety
2. Development of Analysis Methods for Site-Based Risk Studies Using Recent Data
3. Development of Analysis Methods for Vehicle-Based Risk Studies Using Recent Data
4. Development of Comprehensive Roadway Information in a GIS Database
5. Application of OEM Electronic Data Recorders for Risk Studies

Topic 2-2: Risk Studies

1. Instrumented-Vehicle Risk Study—Phase I: Study Design
2. Instrumented-Vehicle Risk Study—Phase II: Pilot Study
3. Instrumented-Vehicle Risk Study—Phase III: Field Study
4. Instrumented-Vehicle Risk Study—Phase IV: Intersection Analysis and Countermeasure Implications
5. Site-Based Risk Study—Phase I: Study Design
6. Site-Based Risk Study—Phase II: Field Study
7. Site-Based Risk Study—Phase III: Analysis and Countermeasure Implications

Topic 2-3: Countermeasure Evaluation

1. Identify Countermeasure Evaluation Topics
2. Retrospective Countermeasure Evaluation Projects

3.6 Appendix C

Listing of Titles of Research Project Statements Developed For FHWA Contract DTFH61-98-C-00075, Guidelines for Signalized Intersections

1. Development of Guidelines for Planning, Implementation and Operation of Innovative Configurations for At-Grade, High-Volume Signalized Intersections
2. Accommodation of Turning Traffic at High-Volume Signalized Intersections
3. Improving Safety and Efficiency During the Change and Clearance Intervals at High-Volume Signalized Intersections
4. Accommodation of Pedestrians and Bicycles at High-Volume Signalized Intersections