### UNIVERSITY: University of Tennessee

### TITLE OF PROJECT: Comprehensive Driver Behavior Assessment under Restricted Intersection Sight Distance

### FEDERAL FUNDS:

<table>
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<tr>
<th>Requested Amount</th>
<th>Proposed Duration</th>
<th>Desired Start Date</th>
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</thead>
<tbody>
<tr>
<td>$31,631</td>
<td>12 months</td>
<td>11.01.2009</td>
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### MATCHING FUNDS:

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<tr>
<th>Source 1: University of Tennessee</th>
<th>Source 2:</th>
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<tbody>
<tr>
<td>$31,631</td>
<td>$</td>
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### DEPARTMENT SUBMITTING PROPOSAL:

PI Name/Title: Professor Lee D. Han, Ph.D.
Address: 112 Perkins Hall
Phone: 865.974.7707
Fax: 865.974.2669
Email: lhan@utk.edu

Signature: [Signature]
Date: 09.02.2009

### SUBCONTRACTING INSTITUTION:

### ADMINISTRATIVE REPRESENTATIVE AUTHORIZED TO CONDUCT NEGOTIATIONS:

Name/Title:
Address:
Phone:
Fax:
Email:

Signature: [Signature]
Date:

### ADMINISTRATIVE ORGANIZATION’S REPRESENTATIVE:

Name/Title:
Address:
Phone:
Fax:
Email:

Signature: [Signature]
Date:

### OTHER REQUIRED SIGNATURES:

Name/Title:
Address:
Phone:
Fax:
Email:

Signature: [Signature]
Date:
Problem Statement

Intersection safety is recognized as a high-priority research area by multiple national research institutes and organizations including: AASHTO, FHWA, TRB, ITE, AAA, STC and many state DOTs. NHTSA’s General Estimates System (GES) data indicate that on average some 2.7 million crashes occur at intersections annually, which is over 42% of all vehicular crashes in the United States. Some 9,200 people die as a result of intersection related crashes each year, and of these near 30% were at signalized intersections, which are nearly 4 times as likely to see fatal crashes than their unsignalized counterparts.

Among numerous intersection safety factors, the provision of intersection sight distance (ISD) is an integral part of accident analysis, intersection design, and traffic control. Adequate ISD should be provided at all intersections to minimize potential conflicts and, hence, crashes of vehicles vying to traverse the same facility. The problem with insufficient sight distance is it does not afford the driver ample time for reacting to potential conflicts or hazards. As a result, the likelihood of crash at such an intersection can be elevated, sometimes significantly. Yan et al conducted a field study on unprotected left turns at signalized intersections and found restricted left-turn sight distance not only can contribute to capacity reduction and delay increase, but also may lead to more traffic conflicts as drivers are compelled to accept less-than-adequate gaps.

AASHTO’s monolith on A Policy of Geometric Design of Highways and Streets, often referred to as “AASHTO Green Book,” has long recognized the safety concerns of restricted intersection sight distance. It identified six scenarios; see below, corresponding to various intersection controls and maneuvers that may have ISD issues.

- Case A - Intersections with no control;
- Case B - Intersections with Stop control on the minor road;
  - B1 - Left turns from the minor road;
  - B2 - Right turns from the minor road;
  - B3 - Crossing maneuver from the minor road;
- Case C - Intersections with Yield control on the minor road;
  - C1 - Crossing maneuver from the minor road;
  - C2 - Left or right turns from the minor road;
- Case D - Intersections with traffic signal control;
- Case E - Intersections with all-way Stop control;
- Case F - Left turns from a major road.

Green Book’s procedures for determining required ISD are mainly based on the time gap acceptances methodology. The required ISD’s are equal to the distances traversed by approaching vehicles at the design speeds during the critical time gap as accepted by 50 percent of the drivers. However, these procedures are rather static and simplistic in
comparison with the actual operation situations in the real world and, hence, have the following shortcomings:

1. The gap acceptance data used for determining critical gaps were collected under unlimited sight distance conditions. Since the driver can see further, he has a longer time to observe the coming traffic. When the driver has restricted sight, even though the required IDS is satisfied, his gap acceptance behaviors are likely to be different.

2. The critical gap procedure per Green Book only reflects the behavior of 50% of the drivers. The other 50%, who do not consider the established critical gap acceptable, are likely to be conservative and/or older drivers. The population of the latter has been on the rise, which exasperates the ISD problem.

3. The required ISD procedure is based on road design speed, which is generally correlated with the 85th percentile operation speed. Thus, the minimum ISD standard is unlikely to meet the actual required sight distance of 15% of the drivers. Furthermore, it is commonly observed that a significant portion of motorists tends to exceed the posted speed limits, which makes the ISD problem more serious.

4. Being a design standard, Green Book only considers static sight obstructions, such as trees, cut slopes, walls, buildings, bridge piers, and longitudinal barriers at intersections. Dynamic sight obstructions, such as opposing left-turn vehicles that may block left-turner’s sight in Case F and adjacent stopped vehicles in through lanes that may restrict right-turner’s sight when turning right on red in Case D, are not taken in consideration at design time.

5. A wide range of potential horizontal and vertical curves leading into and from the intersection, see below, can easily render the accepted ISD standards, which are based on straight highway sections, inadequate.

![Diagram of intersection scenarios](image)

In reality, it is not unusual to find signalized intersections with inadequate right-turn sight distances due to poor safety management or complex geometric conditions. Therefore, there is a research need to assess the adequacy of AASHTO ISD design standards through comprehensive and thorough analyses of changes in driving behaviors associated with available (sufficient vs. insufficient) ISD at intersections. Some of the study parameters include gap acceptance, speed, deceleration/acceleration rates, turn maneuvers, response time, vehicle stop position, traffic rule obedience, etc.
These behavior parameters can be employed to quantitatively explain relationships between available ISD, required ISD, and traffic safety and operation.

**Research Approach**

It is important to study driver behaviors under various scenarios with different intersection controls, geometric design, and sight obstruction types/sizes/locations while performing different driving tasks in order to assess the adequacy of AASHTO ISD design standards. Nevertheless, such a comprehensive study is nearly impossible to conduct in field or on road. Literature review shows that very little previous research was focused on investigating the effects of ISD on driving behaviors at real intersections. One reason is that it is very difficult to select appropriate intersections to conduct comparable experiments for various levels of available sight distances. Another challenge for field experiments is collecting numerous driving behavior data. Instead, in this proposal a matrix of well-designed IDS scenarios will be programmed and tested in the state-of-the-art UT Driving Simulator Laboratory (UTDSL).

UTDSL is housed at the Department of Civil and Environmental Engineering (Room #72, Perkins Hall). The core equipment of UTDSL is DriveSafety’s DS-600c driving simulator system. The UT driving simulator is a fully integrated, immersive, high fidelity driving simulation system designed for use in ground vehicle research and training applications. The UT driving simulator has multi-channel audio/visual systems, 300° wraparound displays, two degrees of freedom motion base, and full-width automobile cab (Ford Focus). It has windshield, driver and passenger seats, center console and dash, full instrumentation, control loaded steering, braking and acceleration, and rear-view mirrors. All three rear view mirrors are provided in the form of mounted LCD panel displays integrated with the cab.

The use of a modern advanced driving simulator for driver-vehicle-environment interaction studies has many advantages over similar real world or on-road driving research. They include experimental control, efficiency, expense, safety, and ease of data collection. UTDSL provides a safe and replicable experimental environment for driving behavior studies.

**Methodology**
Empowered by the UT simulator with highly realistic driving simulation and real-time data recording at 60 Hz, the research team will design virtual driving environments encompassing a matrix of conditions strategically situated at different corners, literally. In this study, we will perform the following tasks using appropriate research methods corresponding to different research stages:

**Task 1: Literature Review**

In order to better perform the simulation analysis, the first step is to perform an extensive literature review on intersection sight distance, including:

- Previous research results in analyses of relationship between ISD and traffic safety and operation,
- Previous research results in analyses of relationship between ISD and driving behaviors at intersections,
- Previous research results of driving simulator experiments for intersection studies.

**Task 2: Simulation Scenario Design**

All AASHTO ISD scenarios with different turning or movement maneuvers at the intersection, intersection control types, and different ratios of available ISD to required ISD will be programmed into the driving simulator system, including:

- Case A - Intersections with no control;
- Case B - Intersections with Stop control on the minor road;
  - B1 - Left turns from the minor road;
  - B2 - Right turns from the minor road;
  - B3 - Crossing maneuver from the minor road;
- Case C - Intersections with Yield control on the minor road;
  - C1 - Crossing maneuver from the minor road;
  - C2 - Left or right turns from the minor road;
- Case D - Intersections with traffic signal control;
- Case E - Intersections with all-way Stop control;
- Case F - Left turns from a major road.

**Task 3: Simulation Experiment Operation**

No less than 40 subjects will be recruited to perform various driving tasks in different driving environment. Every subject should hold a valid TN driver’s license with at least 2 years of driving experience. After the novelty is worn and the driver has become familiar with the virtual environment, the formal experiments will be performed and driving behavior data will be recorded corresponding to the various scenarios and parameters.

**Task 4: Experiment Data Analysis**

Corresponding to the ISD driving scenarios, the dependent driving performance measurements include operating speed, lane offset, steering angle and frequency, deceleration/acceleration rate, acceleration rate, accepted/rejected gap, the number of traffic rule violations, response time, stop position, time to collision, crash happening or
not, etc. The behavior data will be compiled and studied both at aggregated level and individual level to help gain insights and answer the questions posted by this study. The analysis of variance (ANOVA) or multivariate analysis of variance (MANOVA) will be used to statistically investigate relationships of driving behaviors and different levels of available ISD.

**Task 5: ISD Standards Evaluation and Future Research Needs**

Through comparing driving performances at different ratios of available ISD to required ISD in each scenario, the adequacy of AASHTO ISD design standards will be evaluated systematically and quantitatively. Correspondingly, further research needs on enhancing ISD design and traffic safety and security will be identified and recommended for future efforts.

**Task 6: Final Research Report**

Each of the research tasks will be documented in a final report. All research data, methodology, experiment process, findings, conclusions, and recommendations will be summarized into the final research report.

**Qualification of Research Team**

Dr. Lee D. Han, who has previously collaborated with University of Iowa’s National Advanced Driving Simulator team under a Department of Defense project, will serve as the PI of the project. He has conducted research and published in the area of intersection safety and operational efficiency for many years. Dr. Xuedong Yan, renown for his expertise in applying driving simulation for human behavior and traffic safety studies, will serve as the Co-PI of the project. A brand new driving simulator has been installed and will be at their disposal for this study.

The most recent journal publications (2008-09) of the PIs are listed below. Detailed CVs are available upon request.


• Yuan, F. and L.D. Han, 2009. “Improving Evacuation Planning with Sensible Measure of Effectiveness Choices – a Case Study,” Transportation Research Record – Journal of the Transportation Research Board. (accepted for publication)


Student Involvement

A doctoral student, Ryan Overton, will lead a team of undergraduate students to conduct driving simulation activities, collect behavioral data, and perform data analysis. Among the undergraduate students are several Honor Students, who have expressed great interest in pursuing advanced study in the field of transportation engineering.

Technology Transfer

Results of this study will be disseminated to researchers and parishioners via project report as well as peer reviewed journal papers. As a minimum, a TRB paper will be submitted for presentation and publication and a seminar will be given to students and researchers on the findings of this study. Additionally, a paper could be prepared for other journals, including STC’s own Journal of Transportation Safety and Security.
### STC Research Schedule/Timeline

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<th>Task / Month</th>
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<td>2. Simulation Scenarios Design</td>
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<td>4. Experiment Data Analysis</td>
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<td>5. ISD Standards Evaluation &amp; Future Research Needs</td>
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Project milestones should be outlined in this form and will be referenced for compliance purposes in quarterly reports.
# STC Research Project Description

**Project Title:** Comprehensive Driver Behavior Assessment under Restricted Intersection Sight Distance  
**Principal Investigator:** Lee D. Han  
**University:** University of Tennessee  
**Telephone:** 865.974.7707  
**Email Address:** lhan@utk.edu

### External Project Contact (if applicable):
- **Address:**  
  - **Street:**  
  - **City:**  
  - **State:**  
  - **Zip:**  
- **Telephone:**  
- **Email Address:**

**Project Start Date:** 11.01.2009  
**End Date:** 10.31.2010

### Other Milestones, Dates:
- 04/2010: Demonstration to STC staff as well as state/local engineers scenarios of intersection sight distance restrictions with UT’s driving simulator.  
- 10/2010: At least one peer-reviewed journal paper will have been submitted, in addition to the project report, which will be submitted to STC.

### Project Objective:
- To assess driver behaviors under various situations of different driving tasks as a function of restricted intersection sight distance conditions.  
- To identify dynamic scenarios where the current standard (AASHTO Green Book) may be inadequate per the findings in the driving simulation laboratory.  
- To suggest potential design/operational improvements to address the safety risks.

### Project Abstract:
The study will use driving simulator to conduct a comprehensive driver behavior assessment for restricted intersection sight distance scenarios with different control devices, turning maneuvers, horizontal curves, etc. The results will be studied carefully and compared with existing AASHTO design standards to identify potential issues and improve design and operational safety concerns in the future.

### Task Description:
1. Design Simulation Scenarios;  
2. Recruit Drivers and Conduct Simulations;  
3. Extract and Analyze Behavior Data;  
4. Evaluate Results and Compare with Standards;  
5. Explore Future Research Needs;  
6. Prepare Reports and Papers

### Total Budget:
- Federal Share: $31,631  
- Non-Federal Matching: $31,631

### Student Involvement (Thesis, Assistantships, Paid Employment):
A doctoral research assistant, working on dissertation, will lead undergraduate students to conduct scenario design, driving simulation, and data analysis tasks.

### Relationship to Other Projects:
This is a driver behavior related study that builds on UT’s recent acquisition of a driving simulator.

### Technology Transfer Activities:
Journal paper, project report, hands-on demonstration to students, researchers, and engineers

### Potential Benefits of Project:
Attainment of better understanding of expressed driver behaviors at intersections with sign distance problems and, based on this understanding improve design and operational safety.

### TRB Keywords: Safety, Driver Behavior, Sight Distance, Gap Acceptance, High Risk Intersections, Clear Sight Triangle, Driving Simulator, Left Turn
Southeastern Transportation Center
Proposed Budget for 2009-2011
MRI

**Title:** Comprehensive Driver Behavior Assessment under Restricted Intersection Sight Distance

**University:** University of Tennessee

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**Other Direct Costs:**

- Permanent Equipment
- Expendable Equipment and Supplies
- Computer Costs $2,000 $2,000
- Education Costs
  - Graduate Student Stipends
  - Undergraduate Student Stipends
  - Tuition / fees
  - Student health insurance
  - Activity fees
- Other Costs: (specify)
  - Printing / duplication
  - Postal expense
  - Communication
  - Conference Registration / Fees
  - Travel $2,000
- Computer Costs
- Other miscellaneous costs:

| **Total Other Direct Costs** | $2,000 | $4,000 |

**Saving of Indirect Cost from 48% to 26%** $5,523

**Indirect Costs at [26] %** $6,527

**Indirect Cost at 48%** $6,403

**TOTAL COSTS** $31,631 $31,631