The Evolution of Practical Safety Audits in the United States

by

Tegan Marie Houghton

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented April 23, 2008
Commencement June 2008

AN ABSTRACT OF THE THESIS OF

Tegan Marie Houghton for the degree of Master of Science in Civil Engineering
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This thesis evaluates pre-construction auditing procedures used in the United Kingdom, Australia, and New Zealand in order to help create post-construction auditing procedures for the state of Oregon. It was funded as part of the development of the *Oregon Department of Transportation (ODOT) Safety Investigation Manual*, and also evaluates content issues for this document. The final product of this thesis is two worksheet packages on intersection sight distance and decision/dilemma zones that include discussion of the concepts, suggested worksheets for field investigations, and example problems to aid in user completion.

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APPROVED:

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Tegan Marie Houghton, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction

Pre-construction safety audits have been prevalent in the United Kingdom, Australia, and New Zealand for several years. During this time, their auditing strategies have evolved into successful programs with detailed practices on audit team selection, audit development, and what projects warrant the need of an audit. Now, in the United States, post-construction safety audits are becoming more and more common as states allocate funds to rid their roadway networks of site deficiencies that result in an overrepresentation of crashes on their networks. The Oregon Department of Transportation (ODOT) has decided to create a manual, called the *ODOT Safety Investigation Manual*, for the purpose of creating uniform practices in auditing procedures, fund allocations, and mitigation selection. This thesis looks at how to aid ODOT in creating systematic auditing procedures for analysts performing initial site visits at locations determined to be dangerous, as well as the recommended overall format of the manual. Readers will encounter a detailed discussion of pre-construction auditing procedures in other nations, development considerations for the *ODOT Safety Investigation Manual* and worksheet packages, as well as detailed discussion of two such worksheets.

Chapter 2: Background on Safety Audits

2.1: Background on Use

A road safety audit "…is a formal and independent safety performance review of a road transportation project by an experienced team of safety specialists, addressing the safety of all road users" (Wilson and Lipinski, 2004, pg 3). The purpose of a safety audit is to identify safety deficiencies of a roadway design and correct them in order to prevent future injury. Safety audits can be performed during the planning and design of projects, or after a facility has been opened and operational. Often, safety auditing is confused with simply checking for compliance with design standards. Although it is important to identify compliance with standards, the most important benefit of a safety audit is that it checks for the safety concerns not addressed by general standards.

The first roadway safety audits were conducted in the 1980's in Great Britain (Wilson and Lipinski, 2004). In the early 1990's, these practices were also implemented in Australia and New Zealand (Wilson and Lipinski, 2004). According to the Transportation Research Board (TRB), it was not until 1996 that roadway safety audits were first introduced in the United States (Wilson and Lipinski, 2004). Since the United Kingdom, Australia, and New Zealand have had longer to develop their safety audit procedures, their methods will be used to evaluate pre-construction safety audit methods. Although many attempts have been made, the idea of pre-construction safety audits has yet to become common in United States design procedures.

2.2: Benefits of Use

Road safety audits provide many benefits to transportation projects. Both Austroads (2002) and Wilson and Lipinski (2004) have pointed out that safety audits create a greater focus on safety during the transportation design process. Incorporating the use of safety audits encourages planners and engineers to actively consider safety parameters throughout the design stages. While it can be easy for project members to become overwhelmed with other design considerations, the safety audits reinforce the importance of these parameters. Wilson and Lipinski (2004) has also pointed out that safety audits provide opportunity for safety experts to provide feedback to engineers on their current practices. This can be either validation of current performance or highlighting areas that need improvement.

According to Austroads (2002), safety audits are also able to reduce the number and severity of crashes at a location. This is further supported by K.W. Ogden (1996), who states that studies in the United Kingdom have shown safety audits have the potential to remove up to one-third of total future crashes. Another beneficial outcome of safety audit use is they reduce the need for future corrective construction to the site (Austroads, 2002). It is always preferable, and less expensive, to change design plans than to reconstruct existing roadways. Safety audits also yield significant crash savings while generally accounting for less than 0.5% of the total project cost (PIARC, 2003).

Another benefit of safety audits, identified by Wilson and Lipinski (2004), is that they progress roadway design from nominal safety to substantive safety (terms coined by Ezra Hauer). According to Hauer (1999), nominal safety is the type of safety created by design compliance to current standards. However, each roadway location is distinctive in its need for safety accommodations, and substantive safety looks at going beyond just the safety standards to adding improvements customized to the needs of each location. Even if a location meets safety and design standards, it may not actually be safe for roadway users.

Finally, safety audits provide for input from interdisciplinary agencies that might otherwise not have input in the design process (Wilson and Lipinski, 2004). Examples of these groups include multimodal activists, Americans with Disabilities advocates, emergency service representatives, human factors professionals, etc. These supplemental users can provide needed safety suggestions beyond those typically voiced by design professionals.

Chapter 3: Pre-Construction Safety Audit Practices

Discussion of safety audit practices as the pre-construction phase has been broken down into the categories of audit team composition, timing of audit performance, and format of the audit process.

3.1: The Safety Audit Team

In order to perform a traditional pre-construction safety audit, an independent audit team must be identified. The audit team is the group of individuals (with respective specialties) that will be evaluating the project design to ensure adequate safety has been provided. Effective composition of the safety audit team is crucial to producing quality audit reports. The following sections identify and evaluate the audit team composition strategies practiced in the United Kingdom, New Zealand, and Australia.

3.1.1: United Kingdom Methodology

In the United Kingdom, the audit team is compiled of four types of members. These member classifications are the team leader, team member, the observer, and the specialist (Wilson and Lipinski, 2004). According to the Wilson and Lipinski (2004) study, a minimum of two members are required for each safety audit team.

The safety audit team leader has the most extensive experience requirements. To begin with, team leaders are required to have a minimum of four years experience in either safety analysis or crash investigations. They are also expected to have at least two days of continued education in safety audit procedures, crash investigation, or general safety practices (Wilson and Lipinski, 2004). Finally, team leaders are required to have completed five safety audits within the last year to remain current with practices (Wilson and Lipinski, 2004).

The United Kingdom requires audit team members to have at least two years experience in either safety analysis or crash investigation (Wilson and Lipinski, 2004). They also require a minimum of two days continued education in safety audit practices, crash investigation, or general safety (Wilson and Lipinski, 2004). Additionally, the United Kingdom expects all team members to have completed at least five safety audits in the past two years, yielding a minimum of ten days experience in safety auditing (Wilson and Lipinski, 2004). Participation can be completed as either team members, team leaders, or observers (Wilson and Lipinski, 2004).

Two additional contributors to the safety audit team are the observer and the specialist. According to the United Kingdom, the observer should have at least one year of experience in safety audit procedures, safety analysis, and/or crash investigation (Wilson and Lipinski, 2004). The United Kingdom procedures also request ten days of training in any of these same subjects (Wilson and Lipinski, 2004). According to the Wilson and Lipinski (2004) study, the role of the observer is to assist and observe the audit process so they may eventually qualify for member status.

The specialist is an outside resource to the audit team. While not technically a member of the audit team, this specialist will provide expertise on an as needed basis (Wilson and Lipinski, 2004).

3.1.2: AUSTROADS Methodology

Austroads (2002) has identified two different positions for audit members in New Zealand and Australia: team leader and team member. According to Austroads (2002), a team leader must have adequate experience in his or her study area to be able to work on the specific project stage being analyzed (i.e. planning versus final design stage), and meet the qualifications of a Senior Road Safety Auditor.

Austroads requires Senior Road Safety Auditors to complete a two-day, recognized training program in auditing (Austroads, 2002). They also require a minimum of five years experience in road design, construction, or traffic engineering (as applicable to each type of project), and must have contributed to at least five audits (three of which must have been conducted during the design stage). Finally, to keep their experience current, one of the five must have been conducted in the past year (Austroads, 2002).

Austroads (2002) does not have any criteria specified for team members, but points out that they should be selected based on their area of emphasis and its relevance to the project under evaluation. Contrary to the United Kingdom’s methods, New Zealand and Australia do not have a special category for auditors in training (the United Kingdom calls these individuals ‘observers’). Rather, Austroads (2002) says that being a team member on an audit team is a good way to gain experience in learning about auditing procedures.

3.1.3: Specialties Involved

According to the Wilson and Lipinski (2004) study, a 'core team', including a safety analyst, roadway designer, and traffic engineer, should typically be used for each audited project. They point out that other team members can be added to this core, depending on the demands of the project. These additional members can include planners, law enforcement, multimodal specialists, human factors analysts, and local road users. Echoing this idea is Austroads (2002), who identifies that for New Zealand and Australia the road safety audit teams should contain representatives of safety engineering, traffic engineering/management, roadway design, roadway construction, and roadway user behavior specialists.

3.2: When to Perform a Safety Audit

Safety audits can be useful during many different stages of project development. These include planning, preliminary design, final design, traffic control device construction planning, construction, and the construction completion stages. The following sections summarize these different auditing stages and how to identify which projects to audit.

3.2.1: What Stage of Project Development

Planning

Austroads (2002) and the Wilson and Lipinski (2004) study both identify the planning stage as suitable for auditing. According to Wilson and Lipinski (2004), things to evaluate during the planning stage include: project scope, alignment location and preliminary layout, intersection designations, access spacing and control, and projected impact on surrounding land use and infrastructure.

Preliminary Design

Another analysis stage identified by the Wilson and Lipinski (2004) study and Austroads (2002) is the preliminary design. In fact, Wilson and Lipinski (2004) says this is a required audit stage in the United Kingdom. At this stage, the project can be evaluated for compliance with relevant design standards (Wilson and Lipinski, 2004). Areas evaluated include: horizontal and vertical alignment, intersection layout, sight distance, typical section widths, use of superelevation, multimodal factors, and human factors (Wilson and Lipinski, 2004).

Final Design

The final design stage is also a safety audit analysis stage identified by Wilson and Lipinski (2004) and Austroads (2002). Similar to the preliminary design stage, this step is also a required audit stage in the United Kingdom (Wilson and Lipinski, 2004). Safety audits at this stage evaluate final geometrics, signing and striping plans, lighting plans, landscaping, detailed layout of intersections/interchanges, drainage plans, roadside objects, etc (Wilson and Lipinski, 2004).

Traffic Control Device (TCD) Construction Planning

The TCD stage is outlined by Wilson and Lipinski (2004) and involves analysis of the traffic control plans for the construction phasing. A safety audit at this stage would consider different TCD alternatives, devices, temporary geometry, etc (Wilson and Lipinski, 2004).

Construction Stage

The construction stage is another auditing stage identified by Wilson and Lipinski (2004) and Austroads (2002). This stage involves evaluation of construction phasing interaction with utilities, railways, local businesses, maintenance procedures, etc (Wilson and Lipinski, 2004). This stage can also be used to evaluate different construction staging options (Wilson and Lipinski, 2004).

Construction Completion

According to the Wilson and Lipinski (2004) study, the United Kingdom requires that all projects include an additional safety audit after completion of the project construction.

3.2.2: Which Projects Should be Audited

Austroads (2002) has identified three ways of determining which projects should receive safety audits. First, jurisdictions can require a percentage of all projects on major roadways to be audited. Second, jurisdictions can require all projects over a certain project cost threshold to be audited. Finally, an agency or jurisdiction can require a certain percentage of all projects over a project cost threshold be audited. According to Wilson and Lipinski (2004), New Zealand allows agencies to require all projects within their jurisdiction to be audited, unless it is determined unnecessary. As Wilson and

Lipinski (2004) identifies, “Today in New Zealand, the current policy of Transit is to apply RSAs [road safety audits] to all projects and to allow for exceptions if the project manager believes that an RSA is not necessary. Documentation is required if the decision not to conduct an RSA is made” (pg 23). For clarification purposes, Transit is the New Zealand agency that oversees all state highways.

In the United Kingdom, they require that all projects on major highways have road safety audits performed (Wilson and Lipinski, 2004). According to Wilson and Lipinski (2004), they also require all projects having had a road safety audit to participate in a road safety audit monitoring process, which evaluates the effects of the road safety audits at 12 and 36 month intervals after completion. “Such a monitoring process focuses on linking crash characteristics and audits to help future RSA [road safety audit] activities to reduce crashes” (Wilson and Lipinski, 2004, pg 21).

3.3: Development of a Traditional Safety Audit

Nine key steps are associated with the development of traditional safety audits in the United Kingdom, Australia, and New Zealand. While not all three countries require the same steps, overall nine are suggested for consideration. These steps are outlined in Figure 1 and the following sections.

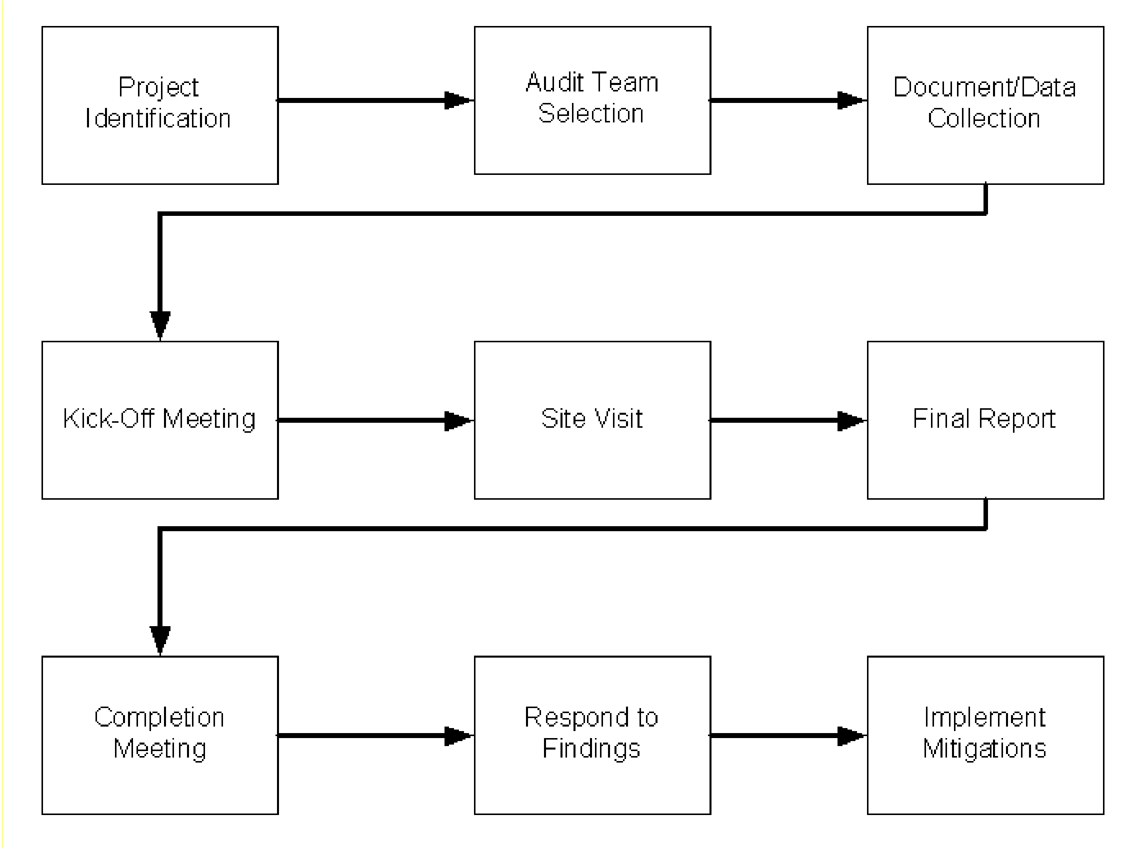

Figure 1: Traditional Safety Audit Procedure

Step 1: Project Identification

The first step of the audit process, identified by Austroads (2002), is to identify a project in need of auditing. This can be the result of jurisdiction requirements or a decision made by the project team due to location or attributes of the project.

Step 2: Audit Team Selection

The second step identified by Austroads (2002), and the first step identified by the Wilson and Lipinski (2004) study, is to select an appropriate audit team for the project. The audit team size and expertise will vary based on project demands.

Step 3: Document/Data Collection

Once the audit team has been selected, the first order of business is to retrieve necessary analysis materials from the project group. According to the Wilson and Lipinski (2004) study, this step also includes retrieval of a statement of scope for the audit, which is created by the project team. Typical documents collected in this step are: project plans/drawings, design standards identified as applicable, traffic volume counts or data, crash statistics (for redesigns or project updates), etc. (Wilson and Lipinski, 2004, pg 7). These documents are then used to perform analysis of the design, along with information collected at the site visit. Austroads (2002) has also suggested that sections of the applicable contracts, design project intent, any standard compromises and justifications to date, land use information, environmental concerns (i.e. historic buildings or endangered species), and any documents from previous road safety audits for the site be collected. Both Wilson and Lipinski (2004) and Austroads (2002) have also suggested collecting community input or concerns about the project.

Step 4: Kick-Off Meeting

The kick-off meeting has been identified by Austroads (2002) and Wilson and Lipinski (2004) as a good way of introducing the audit and project teams. Austroads (2002) also mentions it can be helpful to invite the project client to the meeting. The meeting is a good opportunity for the groups to discuss the audit scope, roles and responsibilities of different individuals, and presentation format of the findings (Wilson and Lipinski, 2004, pg 7). The project team should also let the audit team know of any existing project design concerns they have, important environmental conditions to observe (i.e. peak hours), etc. (Austroads, 2002).

Step 5: Site Visit

After participating in the kick-off meeting, the audit team should begin their site visit(s) (Austroads, 2002, and Wilson and Lipinski, 2004). Austroads (2002) suggests that during the site visit(s) the background documents and data collected in Step 3 be assessed for validity, and in the event that questions are raised the project team should be contacted. Also, prior to site inspection, they recommend going through the documents and data and compiling a list of things to check at the site. Austroads (2002) also recommends conducting daytime and nighttime site visits. Wilson and Lipinski (2004) adds to this that when evaluating the project site the adjacent roadways should also be considered.

Once the site visit has been completed and the documents have been collected, auditors have the tools necessary to complete their analyses. The following tables provide summaries of design characteristics suggested by Austroads (2002) for review during such analyses.

Table 1: Traditional Safety Audit Checklist

General Considerations	Design Issues	Intersections
• Project Scope • Access Management • Trip Generators • Roadway Drainage • Weather Constraints • Landscaping • Adjacent Land Use • Emergency Vehicle Considerations • Relation to Future Planned Projects • Maintenance Requirements • Locations for Emergency Stop (e.g. broken cars) • Friction Factors • Cut and Fill Stability • Contrast of Roadway Markings • Use of Speed Zones • Nighttime Driving Considerations • Turning Radii • Roadway Tapers	• Route Selection • Roadway Continuity • Design Standards • Design Speed • Design Volume • Design Traffic Characteristics • Typical Sections • Cross Sections • Roadway layout • Shoulder Type • Edge Treatments • Sight Distance	• Number of Intersections • Type of Intersections • Sight Distance • Intersection Layout • Driver Expectancy • Roundabout Use • Signal Considerations • Signal Display • Movements • Islands

Table 2: Traditional Safety Audit Checklist (continued)

Multimodal Considerations	Traffic Considerations	Alignments	Other
• Adjacent Land Use • Pedestrian Requirements • Bicycle Requirements • Motorcycle Requirements • Equestrian Requirements (if applicable) • Truck Requirements • Public Transportation Aspects • Elderly Pedestrians • Disabled Pedestrians	• Overtaking • Merges • Rest Areas • Pull-Outs • Medians • Clearzone • Crash Barriers • Operations • Temporary Traffic Control • Signal Considerations • Signal Display	• Horizontal Geometry • Vertical Geometry • Sight Distance • Roadway Tie-In Locations • Driver Expectancy • Bridge Treatments • Culvert Placement	• Roadway Lighting • Sign Requirements • Roadway Markings • Roadway Delineations • Detours • Roadway Ponding

<u>Step 6: Final Report</u>

After completing the site visit and analyzing all documents, a final report should be submitted to the project team outlining the safety issues and deficiencies determined (Wilson and Lipinski, 2004). According to Wilson and Lipinski (2004), this report should also identify recommendations. However, while recommendations should be provided, auditors should avoid redesigning or providing detailed solutions to the project team (Austroads, 2002).

According to Wilson and Lipinski (2004), there is some debate over whether the findings of the report should be presented or communicated to the project team before the final report is submitted. However, they point out that discussing beforehand emphasizes cooperation between the organizations. They also write, “This gives everyone an opportunity to brainstorm conclusions, solutions, and recommendations and have input into the audit report” (Wilson and Lipinski, 2004, pg 8).

Step 7: Completion Meeting

The completion meeting is the project team’s opportunity to discuss the recommendations made by the audit team, work out potential solutions, etc (Austroads, 2002). Wilson and Lipinski (2004) points out that the meeting “…should be an open, positive, and constructive discourse that is free of criticism…” as it can be difficult for designers to receive a critique of their work by an outside party (pg 8).

Step 8: Respond to Findings

After receiving the audit report, both Wilson and Lipinski (2004) and Austroads (2002) have stated that the project team should respond to the safety audit conclusions. These responses should be in written form and convey whether the identified problems have been mitigated (Wilson and Lipinski, 2004). In the event that they are not addressed by redesign, justification should be provided as to why the project team is choosing not to change their design (Wilson and Lipinski, 2004).

Step 9: Implement Mitigations

After responding to the findings, mitigations should be carried out in the design to promote increased safety (Austroads, 2002 and Wilson and Lipinski, 2004). Wilson and Lipinski (2004) says that these implementations should be recorded and kept as part of the overall audit record of the site.

Chapter 4: Developing Post-Construction Safety Audit Techniques

4.1: Introduction

In July of 2007, the Oregon Department of Transportation (ODOT) initiated the development of the *Oregon Safety Investigation Manual*. The manual is designed for use by ODOT safety analysts to use in diagnosing deficiencies at sites with an over representation of crashes. It will also be made available to other agencies that may find its content valuable. While the manual does not describe how to identify these locations, it does set forth methodology for determining possible reasons for the crashes. With this information, it is hoped that ODOT safety analysts will be able to develop mitigations for the site based on their findings.

Because ODOT has several safety analysts, the manual is designed in a way to help systemize the site diagnosis and evaluation. This is done to help remove personal judgment calls about safety, help speed the diagnosis process, and create consistent methodology for all analysts in the event that their decisions are selected for review.

To determine the needs of the analysts, research was conducted on what would be useful for inclusion in the manual. Also, standardized worksheets and supporting text were designed. The worksheets are to be taken to the site and completed by the analysts, while the document text provides background on how to use these worksheets. The following sections outline the methodology behind developing the ODOT Safety Investigation Manual and creating the site-evaluation worksheets.

4.2: Determining Manual Needs

4.2.1: Purpose of the Manual

Within the state of Oregon, there exists a wide variety of safety assessment techniques. These techniques differ between jurisdictions throughout the entire state, creating a consistency issue in determining the extent of safety deficiencies. The (ODOT) mannual allocates funds to different jurisdictions based on the severity of their safety deficiencies. These funds are meant to mitigate the most serious safety problems throughout the state. Since different methods of quantifying safety deficiencies are used throughout the state, funds may not be allocated fairly. Different methods (see appendix for more details) create inherent biases in the results, which means that one location's severity may be rated higher or lower depending on what method is used. When allocating funds, these biases come into play and can result in funds being misdirected to locations that are not as severe as others.

The purpose of the manual is to create a uniform way for analysts to quantify safety throughout the state. This will yield many benefits, one of which is proper allocation of funds by creating a uniform assessment criteria. Other benefits include easy access to methodology for those not trained in safety practices, justification for state level decision making, and proper record keeping for re-evaluations of decisions.

The *ODOT Safety Investigation Manual* is intended for use by ODOT employees or others who wish to determine possible causes of over representation of crashes at Oregon sites. The manual will also provide analysts with typical mitigation strategies once safety deficiencies have been identified at the site. This manual is not intended to aid in the identification of sites experiencing an over representation of crashes, as this is currently provided for by the State Priority Index System.

4.2.2: Review of Existing Manuals

Development of the *ODOT Safety Investigation Manual* first began with a review of existing manuals within other states. Currently, only a few states offer such manuals. The manuals reviewed included the SEMCOG Traffic Safety Manual as well as relevant manuals for the states of California, Idaho, New York, Ohio, and Pennsylvania. For more information on these, please visit the literature review found in the Appendix. The design of the recommended preliminary outline is based on the literature review and engineering judgment. A copy of this outline can be found in the Appendix.

4.2.3: Determining ODOT's Needs

The research team developed a survey for ODOT analysts to complete in order to gather feedback on the preliminary manual outline. The survey asked analysts to identify which of three responses best represented their opinion on inclusion of the topic in the manual. The response options were: “Please Include”; “Not Necessary”; and “Undecided”. Originally, the please include and not necessary responses were going to be the only ones provided. However, the research team added the undecided option for those who were either unsure of whether the topic would be useful, or could not understand from the survey alone what the topic would entail. Also suggested was space for additional comments or suggestions, in the event that the analysts wished to see something in the manual that had not been recommended. One question was also asked on the organization of the manual, and whether it should be organized by site location (intersections, highways, etc.) or type of information (data collection, site investigation, etc.) A copy of the suggested survey questions is included in the appendix. Dr. Dixon and Dr. Monsere took these suggestions and created the online survey for the ODOT analysts. Survey responses were requested via state e-mail addresses. While Dr. Dixon and Dr. Monsere’s topic wording was slightly different and a few questions may have been added/subtracted, the general intent remained the same. Seven ODOT analysts responded to the survey. The following table provides the questions asked of analysts and their responses.

Table 3: Survey Results

	Please Include (%)	**Not Necessary (%)**	**Undecided (%)**
In Office Data Collection			
How to access crash data history	85.7	14.3	0
How to access police reports	100	0	0
How to access road geometry	100	0	0
How to access volume information	71.4	14.3	14.3
Typical Crash Patterns at Study Locations			
Clues to be drawn based on collision type	85.7	0	14.3
Clues to be drawn based on objects involved	85.7	0	14.3
Clues to be drawn based on driver and/or roadway characteristics	83.3	0	16.7
Interpreting and/or drawing a collision diagram	71.4	28.6	0
Typical causes for each identified crash pattern	100	0	0
Guidance on statistical tests and procedures	100	0	0
Site Investigation			
Equipment checklists	85.7	14.3	0
Data collection checklists	100	0	0
How to evaluate and measure items (i.e. running speed, sight distance, etc.)	85.7	14.3	0
Measurement diagrams	100	0	0
Measurement descriptions/step-by-step directions	85.7	14.3	0
Information on when to perform	85.7	14.3	0
How to perform a preliminary “drive-through”	100	0	0
Companion field book (Supplemental data collection forms)	71.4	14.3	14.3
Countermeasures			
Typical countermeasures for common crash causes	100	0	0
Expected Service life of typical countermeasures	71.4	28.6	0
Information on ‘Countermeasure Packaging’	57.1	0	42.9
How to prevent the introduction of new problems	85.7	14.3	0
Prioritization			
Pre-worked Benefit/Cost Ratios	42.9	14.3	42.9
How to calculate Benefit/Cost Ratios	85.7	0	14.3
Crash reduction factors	85.7	0	14.3
Guidance on weighting the severity of crashes	85.7	0	14.3
Steps to prioritize projects	42.9	42.9	14.3
Suggested Documentation			
Worksheets	83.3	16.7	0
Filing System	40	60	0
Where to look for additional guidance on standards and policy	100	0	0

The survey responses provided good information on where ODOT analysts had concerns. It showed what areas are most relevant to their current practices and where they would like to see uniform methods put into place. To reaffirm these results and discuss more specific requests from the analysts, a meeting was held between ODOT and the research team (Oregon State University and Portland State University). Among other things, the meeting provided an opportunity for analysts to identify what kinds of safety concerns they usually need to evaluate in the field (when performing a safety investigation) and what worksheets they would most like to see. These worksheets include:

- Stopping sight distance for trucks on downhill grades
- Issues concerning multilane and single lane roundabout design
- Signal operations (i.e. identify existence of yellow, red, and/or green timing issues, problems with lens placement or size, etc.)
- Testing for pavement friction levels and surface wear
- Access Management
- No Passing Zones
- Illumination
- How to perform speed studies

These suggestions are a great starting point for work on the ODOT Safety Investigation Manual. Before this meeting was conducted, it was also suggested that a worksheet on intersection sight distance be included as well. Work on this worksheet began prior to the meeting.

For each worksheet, a “Topic Package” will be generated. This package will include the worksheet itself, supporting text for the Safety Investigation Manual, example problems, and corresponding figures and tables. The combination of these items will promote clarity of underlying concepts, measurement steps, and qualification of the site's results.

4.3: Development of Worksheets

4.3.1: Purpose of Worksheets

The goal of the investigation manual to is provide consistent practices among analysts, and the best place to start creating these practices is through worksheets. Worksheets can be effective because they ensure that each analyst is performing and assessing field measurements the same way. Different educational backgrounds can lead to different practices and understanding on the proper way to measure transportation safety related values. The combination of the worksheet and the supporting text/figures will provide clear instructions to ensure that each analyst is informed on the correct way to measure quantities. Also, the worksheet and text will provide clear instructions on how to qualify whether a site's values should be determined to be suitable or contributing to unsafe circumstances. This will help to eliminate some of the subjectivity that can lead to different interpretations of test results.

Another reason why worksheets are ideal is that they provide an excellent means of record keeping. If each individual site is evaluated with a series of worksheets, then these worksheets can be catalogued by location. This makes it easy for individuals, both those who reviewed the site and also ones with no experience to the site, to review what decisions were made about the site and why. Keeping with this idea, in the event that litigation is brought against an agency in regards to one of the reviewed sites, these worksheets provide justification for the decisions made.

4.3.2: Worksheet Formatting

One of the greatest challenges in creating these worksheets was developing the original design of the overall worksheet. When deciding how to format the worksheets, several things were considered: ease of interpreting, length, learning styles, and containment.

Ease of interpreting is a very critical element in worksheet design. During a site visit, the analyst is usually involved in multiple tasks. While two of these tasks include completing the worksheet and taking corresponding field measurements, the analyst must also carry equipment and remain alert around moving vehicles. In order to allow the analyst to focus on these other things, the worksheet was designed so that minimal reading would be required. If the analyst spends too much of his or her time reading the worksheet (instead of paying attention to their surroundings), he or she become vulnerable. Therefore, the wording on the worksheet was kept at a minimum. Instead, worksheets were designed using commands instead of complete sentences. Clutter was also eliminated by using a table format and restricting the amount of instructions and graphics presented. More detailed information will be available in the manual, should analysts need more support than what is presented on the worksheet. Also, since most analysts are familiar with the Highway Capacity Manual, similar formatting was used on the safety investigation worksheets.

Another concern was the overall length of the worksheet. The goal was to keep each worksheet at a length of one page (front and back) or less. Minimizing the length of the worksheet forces researchers to identify what items have to be evaluated in the field and which ones can be saved for in the office (under safer conditions). Separating these items can be done, for example, by creating an “in-office” and a “site-visit” version of the same worksheet. The in-office may involve gathering background information on the site or calculations, while the site-visit worksheet allows for field measurements. In this case, each worksheet (in-office and site-visit) could be up to one page (front and back). Another benefit of a shorter worksheet is that it takes less time to complete in the field, which means the analyst is exposed to less risk. Another benefit of shorter worksheets is people generally pay more attention to those measured quantities, whereas longer worksheets sometimes cause people to rush through the measurements in order to complete them faster.

Another consideration is the learning style of potential users. Every individual retains information differently. Some people learn best through text, some through figures, and other learn best with a combination. Therefore, the best way to present the information on the worksheet is through a combination of text and figures. For each worksheet, figures are created demonstrating key measurement concepts. These concepts are then reinforced through supporting text on the worksheet.

Finally, containment of concepts on the worksheets was an issue. A goal of the worksheets is to design them so that all an analysts needs to conduct the field study is the information provided on the worksheet and the equipment. This means that anytime a table or chart is referenced for values, it must be provided on the worksheet. Also, measurement instructions should be included on the worksheet instead of having to take the manual to the field.

Now that discussion has been concluded on the overall design considerations of the worksheets, the following sections will outline in more detail the needs required for specific worksheet topics. These topics include intersection sight distance and decision/dilemma zones.

4.4: Intersection Sight Distance Worksheet

4.4.1: Background on Intersection Sight Distance

Intersection sight distance is the distance a driver stopped on a side road needs to be able to see (either to the left or right) for he or she to make a safe turning maneuver onto a cross street. It is most commonly evaluated at four-legged approaches with stop control on the minor street. The following figure provides an example of where and how intersection sight distance might be measured.

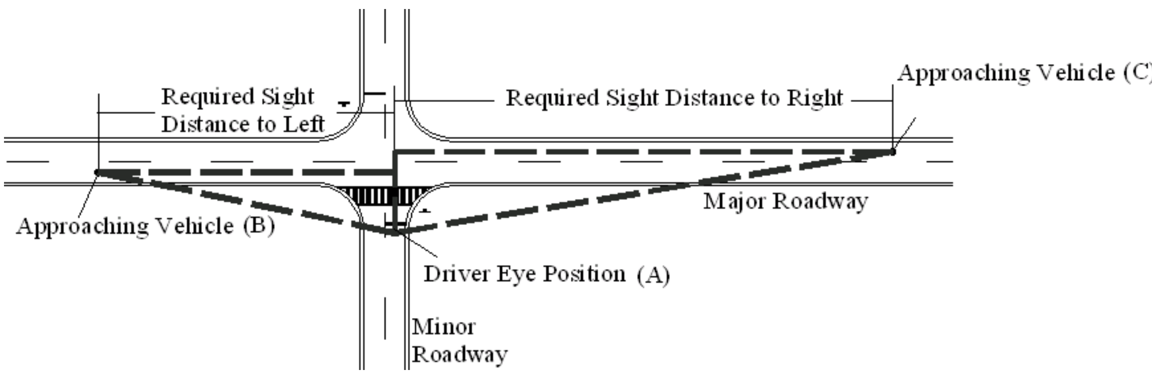

Figure 2: Intersection Sight Distance Plan View

For right turn movements, intersection sight distance is measured to the left. While this may seem counterintuitive, it is because drivers making right turns will need to check for gaps in the approaching traffic (which is approaching from their left). Likewise, for left turns, intersection sight distance is measured to the right. In intersection sight distance, a *sight triangle* is created. The first leg of the triangle extends from the stopped driver's eye position (on the minor street) straight forward until reaching the appropriate center of the lane the driver will turn into. The second leg of the triangle runs down the lane the driver will turn into (either to the left or right) for the full distance of the required intersection sight distance. The end of the intersection sight distance represents the position of the object (in this case an approaching car) the driver must be able to see. The third leg of the triangle is the hypotenuse, and runs from the end of the required stopping sight distance length to the stopped driver's eye position. The area of this triangle represents the entire space a driver needs to have clear from obstructions for he or she to make a safe turning maneuver.

Another key concept of intersection sight distance is the driver's ability to view the object along the entire required sight distance length of roadway. In other words, if the required sight distance at a sight is 300 feet (300 representing the location of the object and zero representing the location in the desired lane directly in front of the driver's eye), the driver should be able to see the object's full height anywhere on the roadway between zero and 300 feet down the road. In the event that the site experiences significant vertical curvature, the ability to see the object at all points may be jeopardized. For example, if the site has a sag curve (creating a hidden dip), the driver may not be able to see the object when it enters this curve. In this case, since the driver looses visibility of the object here, intersection sight distance would not be met.

Proper intersection sight distance is important for maintaining safely operating intersections. Locations that do not have proper intersection sight distance prevent drivers from being able to safely execute turns. When sight distance is limited, drivers cannot correctly assess gaps in oncoming traffic. Drivers then run the risk of turning in front of a vehicle without the space necessary to complete their turning maneuver and/or accelerate to the roadway operating speed before that vehicle reaches them. Poor intersection sight distance can result in an over-representation of right-angle collisions or rear-end collisions at a site.

4.4.2: Standards Used

The procedures and standards for intersection sight distance calculations are laid out in the *AASHTO Green Book* (2004). This includes methods for measuring intersection sight distance and required intersection sight distance for left turns and right turns based on speed. Two minor changes were made to the intersection sight distance tables provided by AASHTO. Instead of using speed limit to determine the required distance, approach speed was used. This decision was made because drivers rarely travel at the speed limit. Instead, it is more conservative to base the required sight distance on the actually approach speed of the vehicles (which is determined using speed studies). Finally, the required sight distance for speeds of 80 miles per hour was less than the required stopping sight distance at 80 miles per hour. Intersection sight distance should always be equal to or greater than stopping sight distance. In the event that a stopped vehicle pulls out in front of another car, it is important that the approaching vehicle be able to see this entering car and stop in time. Therefore, the intersection sight distance at 80 miles per hour was made equal to the stopping sight distance at 80 miles per hour.

The only value researched beyond the AASHTO provided information is the set back value for the placement of the driver eye position. The AASHTO document did not provide clear distinction between whether their recommended driver eye position was for locations with or without crosswalks. Since locations with crosswalks will cause drivers to stop farther back from the cross street, this makes a difference in the setback value (measured from the edge of roadway of the cross street). The AASHTO recommended set back is 14.5-18 feet. To determine what value was appropriate for locations with and without crosswalks, I performed a literature review. For details on this, please see the literature review appendix. While the values all ranged from 15-20 feet back, it was still unclear as to what the difference in the range values represented (i.e. when would a person use 15 over 20 feet as the set back). After reviewing the *Guide for the Planning, Design, and Operation of Pedestrian Facilities* by AASHTO, the standards became clearer. According to this guide, when a crosswalk is present the stop bar should be set back about 10 feet from the nearest (first reached by approaching vehicle) crosswalk line. The *AASHTO Green Book* states that in the United States the driver eye position is usually 8 feet back from the front of the car. Since the front of the car will be stopped at the stop bar line, the driver’s eye is located a total of 18 feet back from the crosswalk line. While this value of 18 feet matches that recommended in the *AASTHO Green Book* it measured from a different location. The Green Book states it should be measured from the edge of travel way of the major road, but based on the information in the pedestrian guide, it appears it should be measured from the crosswalk line when present. This indicates that the AASHTO Green Book standards presented are for locations without crosswalks. The AASHTO Green Book states that the most typical value of that range is 14.5 feet back from the edge of travel way, so this value will be assumed correct for locations without crosswalks. The following table illustrates these standards.

Table 4: Driver Eye Position

	Driver Eye Position Set Back
With Crosswalk	18 feet back from edge of crosswalk line that an approaching vehicle would first encounter
No Crosswalk	15 feet back from the edge of the major street.

Once the location of the driver's eye and approach have been established, the sight distance triangles can be drawn. These represent the area needed for visibility. Since the sight triangles represent the area needed to be kept clear in both the horizontal and vertical planes, vertical heights must also be established for the driver's eye and approaching vehicle positions. According to the 2004 *AASHTO Green Book*, the driver's eye and approach vehicle are both represented by a vertical height of 3.5 feet. This means that within the sight triangle, clear visibility must be maintained between the roadway surface and a straight line drawn between the 3.5 feet heights at the driver eye and approaching vehicle positions. This is more clearly shown in the follow section's figures.

4.4.3: Supporting Figures

A critical part of the worksheet generation is the creation of supporting figures. These supporting figures were designed to reinforce the concepts outlined in the document supporting text. A combination of figures and text is provided for the worksheets to take into account different learning styles. Also, the redundancy of providing explanations two ways helps ensure correct understanding of the materials.

Two key figures were created for the intersection sight distance worksheets. The first of these is a plan drawing of the intersection sight triangles as previously shown in Figure 2.

This drawing was designed to help analysts understand the correct placement of the three vertices of the sight distance triangle. It also demonstrates how the driver eye position is affected by the presence of a crosswalk.

The second figure is a profile view of intersection sight distance triangles along the major roadway.

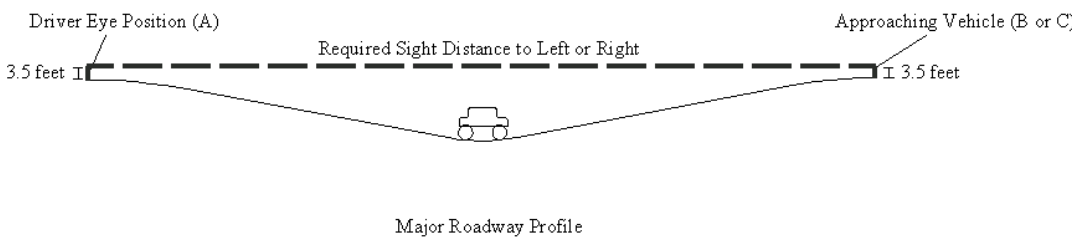

Figure 3: Intersection Sight Distance Profile View

This drawing is particularly important because it emphasizes the need to check for intersection sight distance in the horizontal *and* vertical planes. It is easy for analysts to assume that sight distance is provided if the horizontal plane (or area shown on Figure 2) is provided clearly. However, the vertical plane of intersection sight distance is just as important and needs to be checked separately. At intersections with level terrain/approaches, vertical intersection sight distance is usually met. However, when crest or sag vertical curves are located near the intersection, it can be possible for vehicles to be hidden by the curves in the required sight distance boundaries. Figure 3 shows an example of how a sag curve can hide an entire vehicle.

4.4.5: Example Problems

Example problems included in this topic package (found in the Appendix) include: good typical conditions, poor typical conditions, good horizontal curve, poor horizontal curve, and a vertical curve. The typical conditions example problem shows what a completed form would look like at locations with no extreme circumstances. This type of intersection would have four approaches, two-way stop controlled on the minor approaches, approach grades less than three percent, and no vertical or horizontal curves. A good typical conditions example would show an intersection where intersection sight distance is adequately provided for both (left and right) turning movements. A poor typical conditions example shows an intersection where at least one of the turning movements does not have enough intersection sight distance. In this case, information would be provided on the next steps needed to resolve the problem.

Two more example problems are provided where horizontal curves are located near the intersection. In these problems, the bounds of the intersection sight distance triangles extend into the horizontal curve(s). The presence of horizontal curves complicates the intersection sight distance checks by taking the traditional intersection sight distance triangle and changing its shape. In the event that a horizontal curve is present that curves away from the intersection, the triangle can become split into two pieces because the hypotenuse can cross the intersection sight distance leg and split it in two halves. At sites where the horizontal alignment curves towards the intersection, the triangle may begin to take on more of a half circle shape than a triangle. Since these shapes are different than what is typically experienced, it is important that analysts recognize them and adequately check the entire intersection sight distance triangle. The two example problems included provide analysis of locations where all other characteristics are considered normal, with the exception of the horizontal curvature. Both a location where intersection sight distance is provided and one where it is not are included in the example problems.

The final example problem included is one dealing with a vertical curve. When vertical curves are present they can create locations where the object disappears and the driver cannot see them. This example problem will reinforce to analysts that they need to check for object visibility for the entire length of the intersection sight distance triangle. In this example, the only thing that will not follow typical conditions it that a vertical curve will be present.

4.5: Decision/Dilemma Zone Worksheet

4.5.1: Background on Decision/Dilemma Zones

The terms decision and dilemma zones are often used interchangeably, when in fact they represent two very different scenarios. Decision and dilemma zones are used to qualify the situation drivers are faced when approaching an intersection during its yellow phase. A decision or option zone is present if drivers approaching the intersection are able to recognize the yellow phases and decide whether to stop before reaching the intersection or continue on at their approach speed and pass through the intersection before the conflicting movement receives their green time. Both of these maneuvers must be able to be executed safely. In order for this to happen, the yellow and/or yellow plus all red interval(s) need to be long enough to allow a driver to decide to either enter and clear the intersection when they are far enough back from it to still have enough room available for required stopping sight distance.

In contrast, a dilemma zone occurs when the driver approaching the intersection sees the yellow phase begin and has neither enough time to safely clear the intersection nor enough room to safely stop before entering it. It is referred to as a dilemma zone because either option is dangerous to the passengers in the car and creates a dilemma for the drivers. The presence of a dilemma zone indicates an engineering design error that should be taken quite seriously.

The presence of dilemma zones, which are obviously dangerous, can result in an overrepresentation of crashes at intersections. Drivers who attempt to stop before entering the intersection run the risk of being rear-ended by other vehicles or skidding into roadside objects. Those drivers who attempt to clear the intersection when insufficient time is provided can be involved in right-angle crashes between themselves and conflicting movements that just received their green time.

4.5.2: Supporting Figures

When designing the Decision/Dilemma Zone worksheet, two figures were created for inclusion on the worksheet (found in the appendix). This first figure illustrates the presence of a decision zone.

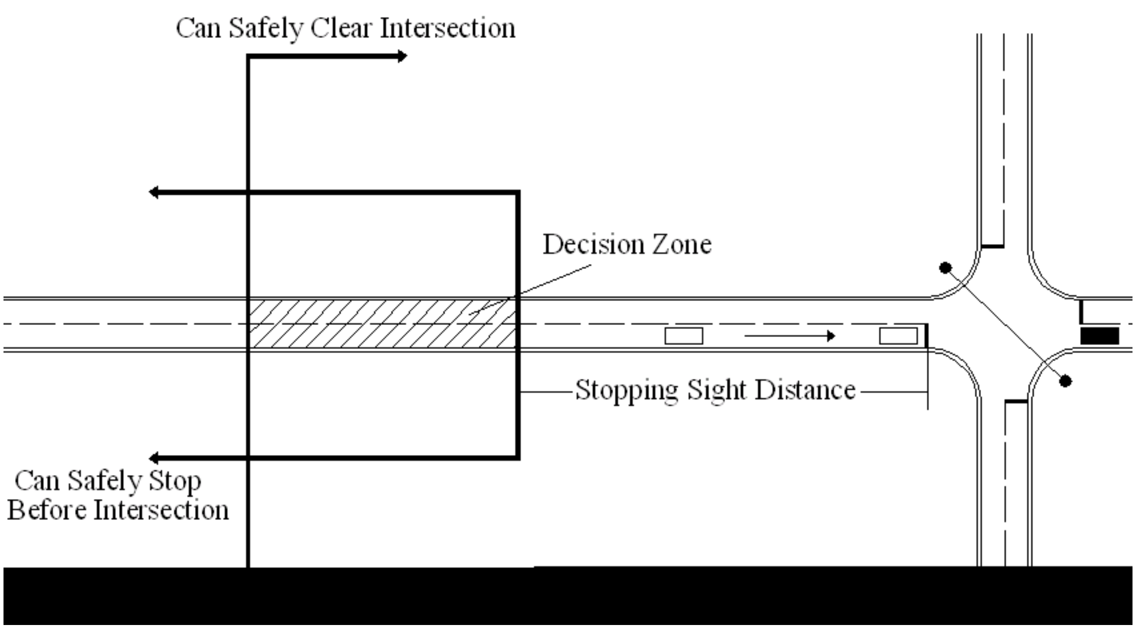

Figure 4: Decision Zone

The key elements of this figure are the locations of the points where drivers need to be located to either safely clear the intersection or stop before entering it. Looking at the figure, we can see that the yellow and/or yellow plus all red interval allows the driver to still decide to clear the intersection before he or she reaches the point where the driver needs to apply brakes to stop safely. The area between these two points creates the decision zone.

The next figure included shows the presence of a dilemma zone.

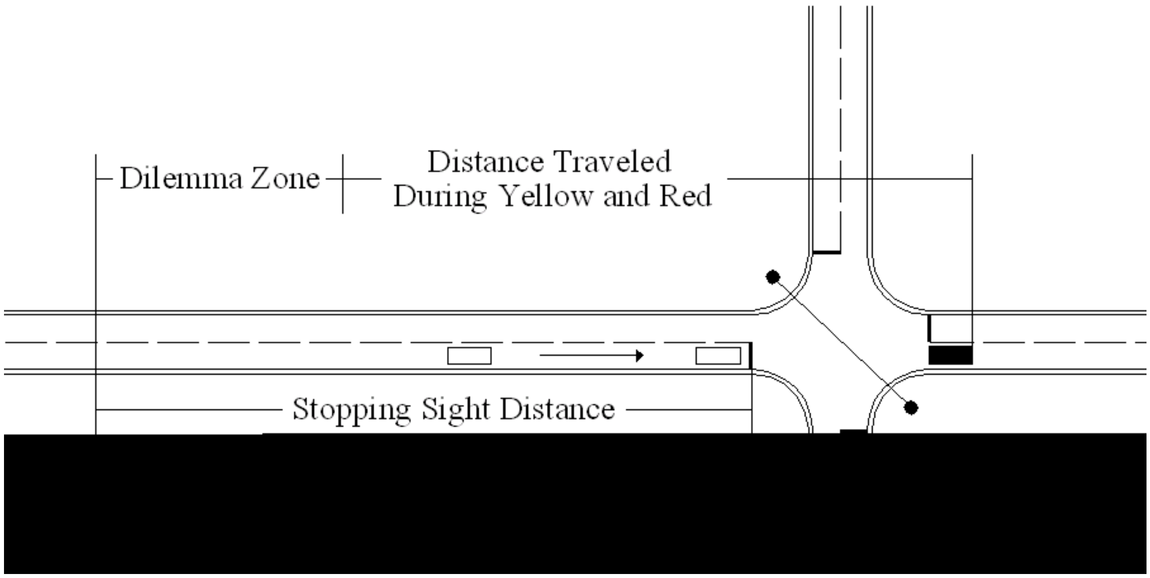

Figure 5: Dilemma Zone

Here, the distance a driver can travel during the yellow and all red interval does not start before the required stopping sight distance. Therefore, drivers approaching the intersection when the signal turns yellow will not be close enough to clear the intersection should they continue at their speed, but they will also be too close to stop before entering the intersection. This area is the dilemma zone.

4.5.3: Example Problems

For this worksheet, four example problems have been included. These four problems include an intersection scenario with a decision zone and a scenario with a dilemma zone for locations with an yellow interval and a yellow plus all red interval. These problems were selected to show analysts both a good and bad example for each type of signal phasing plan. Unlike in the intersection sight distance example problems, there were no particular design considerations that needed to be illustrated other than the phasing combinations between yellow and all red.

4.6: Safety Audit Perspective of Worksheets

4.6.1: When is the "Audit" Performed

In the previous chapter, several possible stages of the design process were identified as opportunities to perform a pre-construction safety audit. Post-construction safety audits can be formed any time after a facility has been constructed. In the context of the *ODOT Safety Investigation Manual*, these worksheets will be used to conduct safety audit procedures after a site has been identified as potentially hazardous.

A site is identified as a potentially hazardous location if it displays an overrepresentation of crashes. Statistically speaking, crashes are bound to happen randomly throughout the roadway network. An overrepresentation of crashes occurs when the number of crashes at the site is shown to be significantly larger than what would be expected by the random occurrence of crashes. To identify these sites, ODOT currently uses the SPIS list.

The *ODOT Safety Investigation Manual* is designed to help safety analysts identify deficiencies in existing and potentially hazardous facilities. Once these deficiencies (if any) are identified, then the manual will help analysts determine appropriate mitigations. While the manual is designed to help analysts select mitigations for the site that will not introduce new safety deficiencies, it is still possible for problems to slip through the cracks. Therefore, it is recommended that prior to construction a design level safety audit be performed to help ensure the best outcome. Furthermore, a few years after the site has been operational (an example would be three years), a study should be conducted to see if the mitigations did in fact result in a decrease in crashes at the location. This is accomplished in terms of a before and after study using crash statistics for the location. Should the results indicate improvements have not been reached, another study should be performed to identify other mitigation alternatives.

4.6.2: The "Audit" Process

The recommended process of this post construction safety audit includes many of the steps found in a pre-construction safety audit. These steps include:

Site Identification

The first step to performing a post construction safety audit is to identify a site in need of examination. Right now the worksheets being developed are more suitable for urban intersections; however, ideally the *ODOT Safety Investigation Manual* will provide worksheets and audit techniques for both rural and urban intersections, as well as roadway corridors.

A site should be considered for auditing if it displays an overrepresentation of crashes on the roadway network. No matter how the roads are designed, a certain number of crashes are expected to occur. However, an overrepresentation at a location results when the number of crashes statistically exceeds the amount expected to randomly occur throughout the network. Currently, ODOT is excising use of the SPIS list.

Selection of Appropriate Worksheets

While this thesis only provides a few safety audit worksheets, it is hoped that ideally the *ODOT Safety Investigation Manual* will include several worksheets designed to address a majority of crash related issues. Once a site has been identified for auditing, the safety analysts should refer to the manual to select the most appropriate worksheets for completion. These worksheets will be selected based on intersection characteristics (i.e. control type, location, etc.) as well as crash trends observed (i.e. over representation of rear-end crashes).

Site Visit/Worksheet Completion

After selecting the appropriate worksheets, a site visit should be performed. This will allow analysts to observe the functionality of the site and to complete the selected worksheets. Scheduling a site visit is a very critical step in determining safety problems. If possible, analysts should visit the site under a multiple conditions. These conditions include: daytime and nighttime, peak-hour and off-peak, poor weather conditions (such as rain), etc. If only one site visit is possible, try to schedule it so that multiple conditions can be seen. For example, to observe both peak-hour and off-peak operations, visit the site an hour before peak-hour traditionally starts.

It is important to complete the worksheets at the site. It may be tempting to gather all required measurements and perform the calculations in an office environment, however, this would be a disservice to the investigation. It is important to know prior to leaving the site whether the worksheets have identified any problems. This way, should a specific problem be identified, analysts can review the site operations and hypothesize potential causes.

Identification of Deficiencies and Suitable Mitigations

Once the worksheets have been completed, a list of site deficiencies should be apparent. This list should be evaluated in relation to the crash statistics for the site to determine which deficiencies are related to which crash types. From this information, analysts can determine what mitigations would provide the best results for reducing the crashes and mitigating the deficiencies. The *ODOT Safety Investigation Manual* ideally will provide information on what types of deficiencies are related to which crash trends to aid analysts in their diagnosis.

Implementation

After determining the most appropriate mitigations for the site, the next step is to implement them. The sooner this is done the sooner a reduction in crashes should be seen.

Follow-Up Study

Finally, after the implementation of the mitigations, it is important to do one final safety audit. This is important because analysts need to ensure that their recommended mitigations actually improved the quality of the site and resulted in the desired crash reductions. Also, it is possible to create new problems for a site based on selected mitigations. A follow-up safety audit will also be able to uncover any unforeseen negative results of the mitigations. Follow-up safety audits should be done after construction is finished, but not right away. It is important to allow road users to adjust to the new environment and to gather new crash statistics for review. Follow-up audits should be performed anywhere from one to three years after the mitigations have been implemented.

4.6.3: The “Audit” Team

The pre-construction audit processes of the United Kingdom, Australia, and New Zealand have rigid requirements on the structure of the audit team. However, the use of the *ODOT Safety Investigation Manual* and corresponding worksheets will not apply such strict requirements on its investigation teams.

While some training of analysts is desirable, the goal of the manual is to be self-contained and self-instructional. Those familiar with safety practices and analysis techniques will find the manual easy to interpret, but those with little experience will also be able to use it as well. The use of safety auditing techniques in the United States is a growing art form so the design of the manual and the worksheets is done with new users in mind.

Therefore, no previous experience with crash investigation, safety auditing, and so forth is required for someone to use to this manual and these worksheets to improve the safety of the state of Oregon.

Furthermore, this method of safety auditing does not need to be completed in teams. The worksheets manual are designed so that a single analyst or multiple analysts can all have success in evaluating sites for safety deficiencies.

Chapter 5: Conclusions

The *ODOT Safety Investigation Manual* provides an excellent opportunity for incorporating safety auditing practices into the state of Oregon. Not only will the document be accessible to many, but it's endorsement by ODOT shows the importance of auditing practices. Over time this will help create a better understanding of how something as simple as a safety audit can benefit many lives.

After completing multiple reviews of the worksheets, the final format appears to provide clear and concise instructions for determining safety hazards. However, it would be helpful to gain feedback from ODOT analysts. Should time and resources permit, it is recommended that analysts review the worksheets and provide comments to promote ease of use before incorporating them into the finished document.

Finally, although this thesis was only able to focus on creating worksheets for intersection sight distance and decision/dilemma zones, many more worksheet topics exist. Over time, it is hoped that worksheets will continue to be generated to help promote a safer transportation infrastructure in the state of Oregon.

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Appendix

Literature Review

Literature Review

Methods for Identifying Overrepresentation of Crashes

Blackspots

Blackspot analysis, sometimes referred to as crash number analysis, looks for areas where large numbers of crashes have accumulated. Blackspots can be used to identify large number of total crashes, types of crashes, or severity of crashes. NCHRP (2003) has pointed out that blackspot identification can be a subjective process, so it is good to set thresholds that blackspots need to exceed to before becoming high crash location. Retting (2001) has identified that blackspot analysis is used in Europe and Australia. Both Retting (2001) and NCHRP (2003) highlight the idea that blackspot analysis may not be unbiased when determining high crash locations. Since blackspots are identified based on high numbers of crashes, locations with higher traffic volume are more likely to be classified as a high crash location and receive treatment than areas with lower volumes. This is a negative result because the areas with lower volumes can sometimes be more dangerous situations.

Severity

High crash locations are sometimes based on the severity of the crashes experienced. One form of accounting for crash severity, suggested by Ogden (1996), is create an index, which represents the crashes weighted according to their severity. NCHRP (2003) suggests evaluating locations by calculating the number of fatal or injury related crashes per unit length. This can be used for sections of highway or point locations.

FHWA (1981) has identified an analysis strategy known as the accident severity method. This method uses crash types, area types, and crash costs by severity to compute an average relative severity index for locations. This method involves moderate to high costs and required junior level engineers for calculations. This method is advantageous because it considers the severity of crashes and works well in rural locations. A downfall of this method is its lack of consideration for high crash *potential*. It also does not take into account how factors other than location contribute to crash severity.

Although taking into account crash severity can be a good thing, Ogden (1996) points out a fundamental issue with ranking crashes based on their severity. Since fatal crashes are usually given higher weight than injury only crashes, sites with high injury numbers are often overlooked in comparisons. The problem associated with this is that the events leading to fatalities are often similar to those leading to injuries. Ogden (1996) asserts that since the events leading to injuries and fatalities are similar, the outcome (injury vs. fatality) is often a result of chance. To avoid discounting injury only crashes too much, Ogden (1996) suggests limiting the weighting of fatal crashes to only two to four times larger than the weighting of injury only crashes.

Rates

Crash Rates

Crash rates are defined as number of crashes divided by the vehicle exposure. According to Ogden (1996), exposure is usually measured with AADT. Resulting crash rates are expressed in two ways depending on location type. For intersections, rates are expressed as crashes per million entering vehicles. For roadway sections, rates are expressed as crashes per million vehicle-miles. This definition of crash rates is consistent with those provided by Graham et. al. (1975), PIARC (2003), NCHRP (2003), and FHWA (1981). According to FHWA (1981), this method requires little manpower and funding.

Several advantages have been identified for using crash rates. First, rates take into account crash frequency and exposure conditions, which makes this a good variation to blackspot analysis. This method is also advantageous because of its simplicity (FHWA, 1981). PIARC (2003) points out that the crash rate method is the most widely used form for identifying high crash locations, which allows for convenient comparisons.

There are also disadvantages associated with use of crash rates. FHWA (1981) points out that it is easy for locations with low volumes to have crash rates that over emphasize their hazard. This concern is echoed by Graham et. al. (1975) and PIARC (2003). Other disadvantages identified by FHWA (1981) include the need for additional data, lack of consideration for both crash severity and crash potential. Concerns voiced by PIARC (2003) include lack of acknowledgement for the random nature of crashes. PIARC (2003) also points out this method assumes the existence of a linear relationship between traffic volumes and crash numbers, which is not the case. This creates a source of error.

Variations

Variations to the crash rate have also been suggested. The first modification is the crash rate indicator, which is identified by PIARC (2003). This method is very similar to the crash rate approach, with the exception that it inflates the components to show abnormally high crash numbers in comparison to traffic exposure. The equation used to calculate the crash rate indicator is: [Crash Frequency x 10^8] / [365 x AADT x roadway section length].

Critical crash rates have also been identified by PIARC (2003). This method evaluates a specific location's crash rate in comparison with the average rate of a group of similar sites and the minimum value required to classify the location as hazardous. Minimum value required is increased as the level of statistical confidence increases. PIARC (2003) states this approach is advantageous because it accounts for the random nature of crashes. Disadvantages identified include overall complexity, lack of severity considerations, and the assumption of a linear relationship, which can cause biases.

Another variation, identified by Ogden (1996), is using rates to account for severity in a method called the casualty crash rate. This value is calculated by taking the total number of fatal and injury crashes and dividing by the square root of the product of the conflicting traffic flows. This approach originates with Sanderson and Cameron (1986).

Rate Quality Control

Another widely used method that involves rates is the rate quality control. This method uses a threshold value, or critical value, to determine whether location crash rates are significantly high. Thresholds are calculated average crash rates using groups of similarly characterized sites. Graham et. al. (1975), Ogden (1996), and FHWA (1981) have identified this method, which is based on the Poisson Distribution.

According to FHWA (1981), this method requires moderate funding and junior level engineers for calculations. FHWA (1981) points out this method does a good job of reducing deficiencies associated with crash numbers and crash rates. Critical crash rates reduce the tendency for crash number analysis to only identify high volume locations. They also reduce the tendency for low volume locations to have overly emphasized crash rates. This method also incorporates a level of statistical reliability previously unseen. Finally, this method has the flexibility needed for changing crash patterns. Although there are many advantages, FHWA (1981) has also identified disadvantages for the rate quality control method. This method is relatively complex, time consuming, and expensive. It also does not take into account crash severity or crash potential.

Crash Frequency

Crash frequency, as defined by PIARC (2003), is the total number of crashes known at a site, and is commonly intermixed with the term crash number. There has been much debate relating to this method. PIARC (2003) points out that this method has the advantage of being simplest form of identifying high crash locations and promotes detection of sites that incur large amounts of crashes. However, this method has a natural bias towards identifying sites only with high volumes and does not account for severity and the random nature of crashes (PIARC, 2003).

In attempts to reduce the bias of this method, several agencies recommend only identifying a high crash location when its crash frequency significantly exceeds an established threshold. This method is referred to by PIARC (2003) as the crash frequency indicator and by FHWA (1981) as the frequency method. FHWA (1981) identifies the frequency method as one of low cost and requiring minimum manpower. It has the advantages of simplicity and continued monitoring of crashes in the surrounding road networks. Ogden (1996) adds that locations with high crash frequencies have the most potential for reducing large numbers of crashes. However, despite its improvement, this method still does not account for traffic exposure, severity, and crash potential (FHWA, 1981).

Combination Methods

Combination methods have been established to try and mitigate weak spots of the analysis tools. Several different methods of combination have been identified by PIARC (2003). The first of these is the combined threshold method, which requires sites to exceed threshold values of two different analysis methods to classify as high crash location. The individual threshold method uses a combination of two thresholds but only requires that one be exceeded to be considered a high crash location. There is also the individual threshold and minimum criteria method, in which sites are ranked based on one analysis technique and then locations from the ranked list exceeding the threshold of a second analysis technique are considered high crash locations.

A commonly identified combination method is the number rate. This method identifies high crash locations using minimum crash numbers and rates. This method is a combined threshold approach since locations must exceed *both* thresholds to be considered a high crash location. This method has been identified for use by Graham et. al. (1975), Ogden (1996), and NCHRP (2003).

Another combination method is the frequency rate, which is identified by FHWA (1981). This method involves identifying high crash locations based on crash numbers, and then ranks them using their crash rates. According to FHWA (1981), if done manually, this method requires large funding. This method is advantageous because it uses a combination of frequencies and rates, therefore helping reduce their individual weaknesses, while minimizing the number of necessary rate calculations (FHWA, 1981). However, this method is at a disadvantage because of its complexity and required funding (for manual calculations). This method also does not account for crash severity or potential.

Typology

Another way to evaluate crashes is using typology. PIARC (2003) has identified a crash typology indicator that detects high numbers for specific types of crashes in relation to reference indicators. An example of this would be a horizontal curve that is identified as a high crash location because its number of wet pavement crashes significantly exceeds the average for the surrounding road network. Retting (2001) has identified a benefit of using typology methods for identifying high crash locations. Retting (2001) points out that locations with high amounts of specific types of crashes are better suited for successful mitigations than ones with high numbers of crashes overall.

Index

Equivalent Property Damage Only Index (EPDO Index)

This method, identified by PIARC (2003), weighs crashes based on the single most injured person involved. It is meant to prioritize crashes based on severity. Weights are assigned in terms of the number of property damage only crashes required to achieve that same level of loss. Example weights, provided by PIARC (2003), include: property damage only: 1; minor injury: 3.5; and serious injury: 9.5. PIARC (2003) recommends using integers instead of dollar values for weighting because with dollar values it would take large quantities of property damage only crashes to equal a more serious crash, which can cause underutilization. This method has the advantage of accounting for severity while maintaining simplicity (PIARC, 2003). This method, however, does not account for traffic exposure or the random nature of crashes (PIARC, 2003). It also exhibits biases toward rural roads and other high-speed sites (PIARC, 2003).

Relative Severity Index (RSI)

The relative severity index, defined by PIARC (2003), weights crash types based on average severity values obtained from similar crashes. The reasoning behind this method is, “The severity of trauma sustained in any given accident is affected by several factors, such as the impact speed, impact point on the vehicle, type of vehicle, age and health condition of the occupants, protection devices, etc. Consequently, two accidents of the same type occurring at the same location may cause quite different trauma levels" (PIARC, 2003, pg 115). Using averages of similar crashes provides a weight that is less impacted by varying environmental factors. PIARC (2003) points out this method has the advantage of accounting for severity while reducing the effect of externally varying factors. There are also several disadvantages PIARC (2003) cites about this method. Developing a cost grid to compute average-weighting values can be very complex. This method does not account for exposure or the random nature of crashes. It is also biased towards rural locations and other high-speed sites.

Hazard Index

This method develops an index for each location, based weighting of other factors, which is then used to rank locations (FHWA, 1981). Examples of these factors, provided by Ogden (1996), include: rates, frequencies, severities, traffic flow, sight distance, etc. According to FHWA (1981), this method is expensive and requires a lot of employees to collect and maintain data. FHWA (1981) has also pointed out a lot of advantages and disadvantages associated with this method. One advantage is that this method is highly adaptable. It also accounts for hazards caused by location and crash potential. Aside from these advantages, this method requires a significant amount of information. Furthermore, when this information is not readily available (causing factors to be omitted), this method looses its effectiveness. This method also requires significant knowledge in highway safety and human factors.

Prediction Models

Analysis tools are also available that require predictions of expected crashes at locations. PIARC (2003) describes crash prediction models as a way to estimate crashes from independent variables. Geometric features are considered to be an influence. For more information on procedures, PIARC (2003) recommends reviewing Ezra Hauer's 1997 and 2004 publications. Crash prediction models are good because they help improve the accuracy improvement potential estimates (PIARC, 2003). However, they are very complex and do not account for the random nature of crashes (PIARC, 2003).

Retting (2001) describes a way to predict crash numbers by using trends from surrounding areas. This method calculates expected numbers of crash types at an intersection by multiplying the total crashes experience at the site by the total number of this particular type of crash at all surrounding intersections, and then dividing by the total number of crashes at the surrounding intersections.

Both Retting (2001) and Ogden (1996) suggest identifying high crash locations by looking at the difference between the expected (or predicted) number of crashes and the experienced. Ogden (1996) suggests prioritizing sites based on potential for crash reduction, which is this calculated difference. Ogden (1996) points out this method is good because it focuses on ability for improvement, but it can be difficult to get accurate results because of the uncertainty in estimates.

8.9: Empirical Bayesian

The Empirical Bayseian method, identified by PIARC (2003), is a method calculates an adjusted crash frequency for sites by comparing the site's crash history with those having similar characteristics. This method bases itself on the idea that a location's safety is related to its characteristics. PIARC (2003) recommends performing this analysis using multivariate statistical models and methods outlined by Ezra Hauer. An advantage of this method, identified by PIARC (2003), is this method identifies the potential for improvement at locations. PIARC (2003) and Retting (2001) both agree this method is advantageous because it avoids biases created from regression of the mean by accounting for the random nature of crashes. The only disadvantage of this method has been identified by PIARC (2003) and lies in it complexity.

Crash Patterns

Crash patterns are used to determine high crash locations, which involves identifying deviant patterns. This method is based on the properties of binomial distribution and is best suited for areas with high traffic volumes. This method is typically used to identify crash patterns for the most frequent collision types, but as PIARC (2003) points out, " If a clear accident pattern can be found for which a cost-effective treatment is known, an action may be justified even though the overall accident frequency is not abnormally high" (pg 122).

Hazardous Roadway Features Inventory

Hazardous roadway features inventory is a method identified by FHWA (1981) for selecting sites for improvement with high crash potential. Sites with high crash potential are identified based on a comparison between the site's roadway features and those specified in the AASHTO 'Yellow Book'. This method is expensive and requires a lot of engineers to achieve. FHWA (1981) states that this method has an advantage because it considers crash potential for locations where crashes may not have occurred and where the crashes could result in high-severity injuries. A disadvantage, however, is this requires a lot of data and people with experience to complete (FHWA, 1981). Also, any planned mitigations usually need to be justified by a second means (FHWA, 1981).

Cost

Cost is another factor used to determine if a place should be considered a high crash location. In a method described by Ogden (1996), locations are evaluated based on the annual cost of the crashes experienced there. The costs can be determined from nationally set average values.

Other

Graham et. al. (1975) identifies a method known as Early Warning Analysis, which provides immediate monitoring of locations. To conduct this method, keep a chronological list of crashes at each location. When a new crash is added to that location, review the previous three to six months listed (including the month of the newly added crash report) to detect high crash numbers. According to Graham et. al. (1975), performing this step will help identify high crash locations and corresponding issues with any roadway updates recently performed.

Before and After Studies

Before and after studies, which look at crash patterns at a site before and after improvement, are a way to evaluate whether a change has occurred at a site. Graham et. al. (1975) points out that use of before and after studies aids in fine-tuning prediction methods for countermeasure selection. Graham et. al. (1975) identifies four key steps that need to occur prior to conducing a before and after study, which are: crash data for the after comparison need to be available for the same duration of time used for the before analysis; ADT needs to be available to allow adjustments for exposure; both time periods need to have a steady composition of traffic flow; and the crash values are able to be adjusted for surrounding trends. Ogden (1996) recommends having an after period evaluation three years after the countermeasure installation is completed. Ogden (1996) states that three years is sufficient time to see trends establish.

Ogden (1996) has identified several experimental design challenges associated with the before and after comparison. The first he identifies is seasonal fluctuations, both is traffic trends and is weather. Ogden (1996) points out that these fluctuations can affect crash results. He also points out that changes can occur in the road network (like speed). Ogden (1996) states that because crashes are random events, they will fluctuate regardless of the countermeasure used. Ogden (1996) also states that even when the before and after studies show a statistical correlation, it does not mean that they are logically related. Ogden (1996) also says that control sites are useful and necessary to account for changes in local trends, so as not to attribute their effects on crashes to the countermeasure. Ogden (1996) has identified a control site as a location selected because of its similarity to the before/after site location, but that does not receive treatment. According to Ogden (1996), the following criteria should be met for a selected control site: similar roadway geometry, land use, network configuration, etc; location that is close to the before/after site; similar traffic flow; far enough away that it does not receive any impact from the before/after site countermeasure; receives no roadwork during the before and after analysis periods; and have crash data for the before period that are consistent in collection and recording techniques with the before/after location.

Review of Existing Manuals

To get an idea of what should be included in the *ODOT Safety Investigation Manual*, several other states' were reviewed for information on their safety procedures. The review was conducted using official state websites to see whether they provided any guidance on safety procedures and what information they chose to include. The following is an outline of the information found at the randomly selected state websites. These websites were reviewed on July 10, 2007.

California DOT (http://www.dot.ca.gov)

The state of California provides a safety manual which includes safety procedures. They also provide training courses for their analysts and a companion user manual. Topics covered include: crash investigation and data sources, collision analysis, traffic control device use and placement, roadside safety evaluation, wet pavement collisions, "Thinking Outside the Cube", checklists, and legal considerations.

Idaho DOT (http://itd.idaho.gov)

The state of Idaho provides a Safety Evaluation Instruction Manual. This manual provides information on how to develop a safety index through crash analyses. This can in turn be used to prioritize their safety projects.

New York (https://www.nysdot.gov/portal/page/portal/index)

The state of New York provides a Safety Investigation Procedure Manual. This manual provides information on: crash data collection, crash history analysis, field examination, alternative development, and recommended improvements.

Ohio DOT (http://www.dot.state.oh.us)

The state of Ohio provides two key safety documents to its analysts. The first document is the Safety Study Guidelines. This document provides information on: existing conditions analysis, collision diagrams, crash data, crash analysis, recommendations, and benefit analysis. The second document is the Ohio Corridor Safety Manual. This document details how to identify corridor improvement projects, the corridor safety study process, an engineering countermeasure “toolbox”, project implementation, and project evaluation.

Pennsylvania DOT (http://www.dot.state.pa.us)

The Pennsylvania DOT provides two documents to safety analysts. These documents are the Collection of Perishable Crash Data Procedure Guidelines and the Pocket Guide.

SEMCOG (Southeast Michigan Council of Governments)

The SEMCOG manual was put together by the Southeast Michigan Council of Governments. This manual provides a lot of information of safety analysis procedures. The manual provides information on how to identify crash patterns and typical crash causes. Information is included on crash patterns based on collision type, objects involved, and driving characteristics. They also provide a worksheet for identifying patterns and one for identifying causes. The manual also provides information on selection of countermeasures by using the information collected on possible causes and crash patterns. Following this the manual delves into cost/benefit analyses, suggested methods of documentation for the analysis procedure, how to compute crash reduction factors, countermeasure packaging (or putting more than one countermeasure option into use at a time), and use of severity weighting. The manual also provides information on the cost of crashes (Human Capital Method and Willingness-to-Pay), benefit/cost ratios with uniform annual benefit and cost methods, present worth of benefits of costs methods, and countermeasure/project prioritization.

Driver Eye Position

There are two key placement issues associated with driver eye position. The first is vertical positioning. According to the 2004 AASHTO *Green Book,* both the driver eye position and approaching object position should be represented vertically by a height of 3.5 feet. The other important aspect of driver eye position involves its horizontal set back from the minor street intersection with the major roadway. The 2004 AASHTO *Green Book,* the driver eye position should be 14.5-18 feet back from the edge of the major roadway travel way. This is further broken down to 8 feet from the driver’s eye to the front of the car, and 6.5 – 10 feet from the front of the driver's car to the edge of the travel way or stop bar. The AASHTO *Green Book* is not specific, however, on what standards for placement should be used when a crosswalk is present. To further investigate this issue, the AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* was reviewed. After reviewing this document, it became clear that at signalized intersections, the stop bar should be placed 10 feet back from the crosswalk edge first encountered by an approaching vehicle. If the assumption is made that the driver will stop the front of their vehicle at this stop bar, and the distance from the front of their vehicle to their eye is still 8 feet, then the set back from the edge of the travel way will be 18 feet when a crosswalk is present. Therefore, the standards in the AASTHO *Green Book* of 14.5 – 18 feet set back were designed to include an upper limit setback distance for the presence of crosswalks.

List of Acronyms

List of Acronyms

AASHTO: American Association of State Highway and Transportation Officials

NCHRP: National Cooperative Highway Research Program

ODOT: Oregon Department of Transportation

PIARC: World Road Association

RSA: Road Safety Audit

SEMCOG: Southeast Michigan Council of Governments

SPIS: Safety Priority Index System

TRB: Transportation Research Board

Preliminary Outline

ODOT Safety Handbook Topic Outline

Body of Handbook

1. Data Collection
2. Site Investigation
3. Identifying Crash Patterns
    a. Collision Type
    b. Objects Involved
    c. Driving/Roadway Characteristics
4. Typical Causes of Specific Crash Patterns
5. Countermeasure Selection using Typical Causes and Crash Patterns
6. Countermeasure Packaging
7. Cost/Benefit Analysis of Listed Countermeasures
8. Procedure for additional Cost/Benefit Analysis
    a. B/C with Equivalent Uniform Annual Benefit and Cost Method
    b. Present Worth B/C Analysis
9. Crash Reduction Factor Computations
10. Use of Severity Weighting
11. Project Prioritization
    a. Net Benefit Method
    b. B/C Ratio Method
    c. Incremental B/C Method
12. Suggested Documentation

Appendix

1. Site Investigation Checklists
2. Crash Pattern Worksheet (based on SEMCOG)
3. Crash Causes Worksheet (based on SEMCOG)
4. Benefit/Cost Analysis Worksheet (based on SEMCOG)
5. Cost Calculations by Crash Type (Human Capital or Willingness to Pay)
6. List of expected Service Life and Cost Data of Countermeasures

Additional Resources

1. Training Course
2. Pocket Handbook for Site Investigation

Survey Questions

Survey Questions

Step 1: Please indicate what you would like to see included in the ODOT Highway Safety Manual.

Topic	**Please Include**	**Not Necessary**	**Undecided**
Data Collection			
How to access crash data history			
How to access police reports			
Site Investigation			
Equipment checklist			
Data collection checklist			
How to evaluate and measure items (i.e. running speed, sight distance, etc)			
Measurement diagrams			
Measurement descriptions/step-by-step directions			
Information on when to perform			
How to perform a preliminary “drive-through”			
Companion field book			
Crash Patterns			
Identification based on collision type			
Identification based on objects involved			
Identification based on driver and/or roadway characteristics			
Crash pattern worksheet			
Typical causes for each identified pattern			
Countermeasures			
Typical countermeasures for typical crash causes			
Expected service life of typical countermeasures			
Cost data for typical countermeasures			
Information on ‘Countermeasure Packaging’			
How to prevent the introduction of new problems			
Prioritization			
Pre-worked Benefit/Cost ratios			
How to calculated Benefit/Cost ratios			
Crash reduction factors			
Severity Weighting			
Steps to prioritize projects			
Suggested Documentation			
Worksheets			
Filing Systems			

Step 2: Would it be better to have the ODOT Highway Safety Manual information organized based on location (i.e. chapters intersections, driveways, highways, etc) or based on type of information (i.e. chapters on data collection, site investigation, etc)?

Step 3: If you have additional comments or would like to suggest something for inclusion in the ODOT Highway Safety Manual, please do so here.

Thank you for your time

Intersection Sight Distance Package

What is Intersection Sight Distance

Intersection sight distance is the distance a driver stopped at a minor approach needs to see (either to the left or right) for them to make a safe turning maneuver onto a cross street. It is most commonly evaluated at four-legged approaches with stop control on the minor street.

For right turn movements, intersection sight distance is measured to the left. While this may seem counterintuitive, it is because drivers making right turns will need to check for gaps in the approaching traffic (which is approaching from their left). Likewise, for left turns, intersection sight distance is measured to the right.

In intersection sight distance, a *sight triangle* is created. The first leg of the triangle extends from the stopped driver's eye position (on the minor street) straight forward until reaching the lane the driver will turn into. The second leg of the triangle runs down the lane the driver will turn into (either to the left or right) for the full distance of the required intersection sight distance. The end of the intersection sight distance represents the position of the object (in this case an approaching car) the driver must be able to see. The third leg of the triangle is the hypotenuse, and runs from the end of the required stopping sight distance length to the stopped driver's eye position. The area of this triangle represents the entire space a driver needs to have clear from obstructions for them to make a safe turning maneuver. At the stopped vehicle position, drivers must be able to see the entire roadway surface of this triangle at all locations.

Why is it Important

Proper intersection sight distance is important for maintaining safely operating intersections. Locations that do not have proper intersection sight distance prevent drivers from being able to safely execute turns. When sight distance is limited, drivers cannot correctly assess gaps in oncoming traffic. Drivers then run the risk of turning in front of a vehicle without the space necessary to complete their turning maneuver and/or accelerate to the roadway operating speed before that vehicle reaches them. Poor intersection sight distance can result in an over-representation of right- angle collisions or rear-end collisions at a site.

In Office Work

Before visiting the site, it is important to identify the presence of key geometrical features. These features include horizontal and vertical curves. Horizontal curves can be identified using aerial photographs. These are often available through the services of Google Maps and Google Earth. When identifying a horizontal curve, locate the point of curvature, point of tangent, and measure the radius of the curve.

Field Work

After completing the in office work, a site visit is necessary to conduct field observations. These observations include measuring out the appropriate intersection sight distance triangle and checking to see that it's entire area is clear of sight distance obstructions. The following bullets provide step-by-step instructions for measuring and checking an intersection sight distance triangle.

- ***Step 1: Roadway Slope:*** From Position A, walk 250 feet to the left/right alongside the major roadway. Place the SmartLevel on ground and record slope.
- **Step 2: Approach Speed:** Remaining 250 feet to the left/right of approach, measure vehicle operating speeds. Use procedures consistent with the ODOT Safety Investigation Manual.
- **Step 3: Required Sight Distance:** Using Table 1.1 or 1.2, look up the required sight distance for the approach.
- **Step 4: Stopped Driver Eye Position (A):** Measure 14.5 feet back from edge of major roadway or, if present, edge of crosswalk farthest from major roadway. Position self in center of approach lane. Unroll 3.5 feet long measuring tape. Position end of tape on roadway surface. Hold tape vertical. Top of tape represents stopped driver's eye position.
- **Step 5: Roadway Object Position (B or C):** Position self in major road through lane closest to (for measurements to the left) or farthest from (for measurements to the right) the minor approach. Walk required distance to the left/right and along path of

lane. At required distance away from approach, unroll 3.5 feet long measuring tape. Position end of tape on roadway surface. Hold tape vertical. Tape represents an entire object the driver's eye should be able to see.

- **Visibility Check:** Person at Position A (with eye at top of tape) should look left/right towards Position B or C. They should have full visibility of the object (tape) at that point and any other location along the roadway surface between them and Position B or C.

If Position A provides clear visibility of the measuring tape at location B or C (and all points between), then visibility is met to the Left (Position B) or Right (Position C).

<u>Intersection Sight Distance Tables</u>

Table 1.1: For grades less than 3% (Driver Eye Height and Object Height of 3.5 feet)

Approach Speed (mph)	Distance to Left (feet)	Distance to Right (feet)
15	145	170
20	195	225
25	240	280
30	290	335
35	335	390
40	385	445
45	430	500
50	480	555
55	530	610
60	575	665
65	645	720
70	730	775
75	820	830
80	910	910

Values from *AASHTO 2204 Policy on Geometric Design of Highways and Streets*, Exhibit 9-55, Design Intersection Sight Distance-Case B1-Left Turn from Stop, Exhibit 9-58, Design Intersection Sight Distance-Case B2-Right Turn from Stop

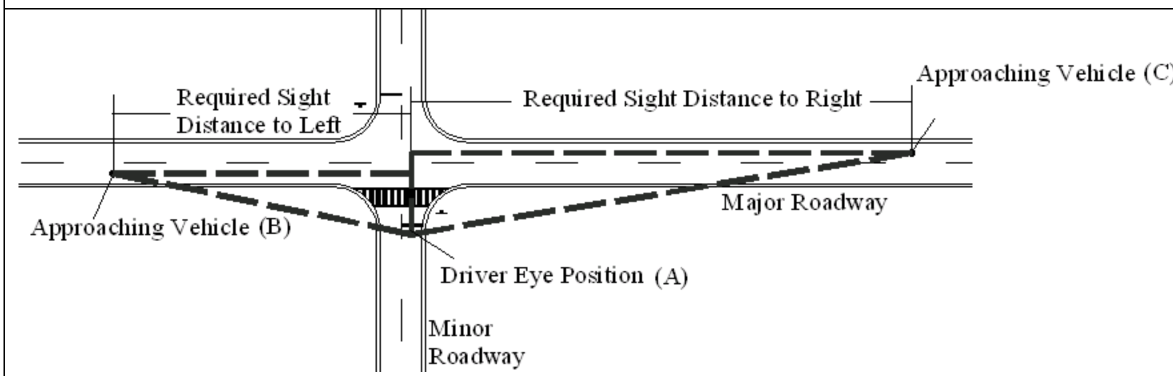
Table 1.2: For grades exceeding 3% (Driver Eye Height of 3.5 feet and Object Height of .5 feet)

Approach Speed (mph)	Stopping Sight Distance (ft)					
	Downgrades			Upgrades		
	3%	6%	9%	3%	6%	9%
20	158	165	173	147	143	140
25	205	215	227	200	184	179
30	257	271	287	237	229	222
35	315	333	354	289	278	269
40	378	400	427	344	331	320
45	446	474	507	405	388	375
50	520	553	593	469	450	433
55	598	638	686	538	515	495
60	682	728	785	612	584	561
65	771	825	891	690	658	631
70	866	927	1003	772	736	704
75	965	1035	1121	859	817	782

INTERSECTION SIGHT DISTANCE WORKSHEET

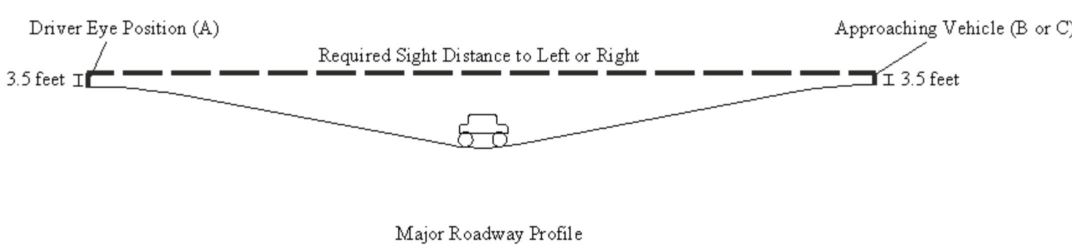
General Information	
Analyst ____________________	Time of Day ____________________
Agency ____________________	Analysis Year ____________________
Date Performed ____________________	Jurisdiction ____________________
Site Characteristics	**In Office Work**
Crosswalk at Approach (Y/N) _________	Horizontal Curve (Y/N) ___________
Sidewalk (Y/N) _________	Approximate Radius (if present) ____
Vertical Curve (Y/N) _________	

Plan Figure



Required Sight Distance to LEFT	**Required Sight Distance to RIGHT**
Roadway Slope to Left _____________	Roadway Slope to Right _____________
Left Approach Operating Speed ______	Right Approach Operating Speed ______
Required Sight Distance _____________	Required Sight Distance _____________
Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) ______	Clear Sight Distance Right (Y/N) _____
List of Obstructions: _________________	List of Obstructions: ________________
____________________________________	____________________________________
____________________________________	____________________________________

Profile Figure



If Position A provides clear visibility of the measuring tape at location B or C (and all points between that), then visibility is met to the left (Position B) and/or right (Position C).

Required Sight Distance Table (less than 3% grade)

Approach Speed (mph)	Distance to Left (feet)	Distance to Right (feet)	Additional Comments
15	145	170	
20	195	225	
25	240	280	
30	290	335	
35	335	390	
40	385	445	
45	430	500	
50	480	555	
55	530	610	
60	575	665	
65	645	720	
70	730	775	
75	820	830	
80	910	910	

Site Sketch
Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

EXAMPLE PROBLEM 1: Typical Conditions 1

Question: Does the intersection approach provide clear right turn and left turn sight distance?

Site Characteristics:

- Four-legged approach
- 90 degree intersection angle
- All vertical approaches are less than 2% slope and no vertical curves are present (i.e. level terrain)
- Two-way stop control (minor streets)
- Sidewalks on all approaches
- Crosswalks present at minor street approaches
- Studied approach is the Northbound approach (Southbound approach performed separately)

Comments: For background information on intersection sight distance, please see Section X of the ODOT Safety Investigation Manual.

Methodology: After identifying key site characteristics, roadway slope and approach operating speed values are used to determine the required sight distance for each approach. This distance is then measured at the site to determine if the required site distance for right and left turns is provided.

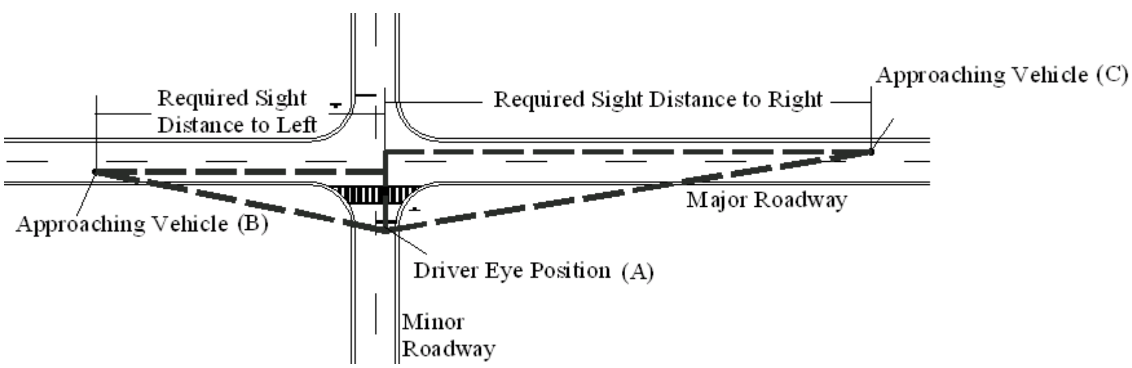
<table>
<tr><th colspan="4">Intersection Sight Distance to the LEFT: Calculated Values</th></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the left alongside the major roadway. At end, place SmartLevel on ground and record slope.</td><td colspan="2">1%</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td colspan="2">44 mph (round to 45 mph)</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td colspan="2">430 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td colspan="2">Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>40</td><td colspan="2">385</td><td>445</td></tr>
<tr><td>45</td><td colspan="2">430</td><td>500</td></tr>
<tr><td>50</td><td colspan="2">480</td><td>555</td></tr>
<tr><td colspan="2">Visibility Check</td><td colspan="2">Visibility is provided for entire distance.</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td colspan="2">Yes</td></tr>
</table>

<table>
<tr><td colspan="3">Intersection Sight Distance to the RIGHT: Calculated Values</td></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the right alongside the major roadway. At end, place SmartLevel on ground and record slope..</td><td>1.5 %</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td>40 mph</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td>445 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td>Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>35</td><td>335</td><td>390</td></tr>
<tr><td>40</td><td>385</td><td>445</td></tr>
<tr><td>45</td><td>430</td><td>500</td></tr>
<tr><td>Visibility Check</td><td colspan="2">Visibility is provided for entire distance.</td></tr>
<tr><td>Is Visibility Met?</td><td colspan="2">Yes</td></tr>
</table>

Completed Worksheet:

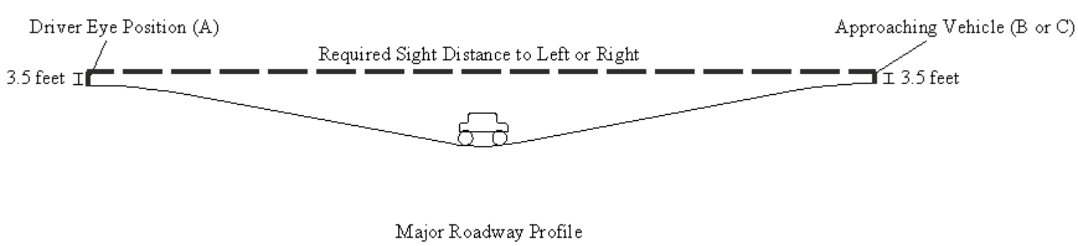
General Information	
Analyst Julia Roberts	Time of Day 2:00 PM
Agency ODOT	Analysis Year 2007
Date Performed December 13, 2007	Jurisdiction Benton County
Site Characteristics	**In Office Work**
Crosswalk at Approach (Y/N) Y	Horizontal Curve (Y/N) N
Sidewalk (Y/N) Y	Approximate Radius (if present) N/A
Vertical Curve (Y/N) N	

Plan Figure



Required Sight Distance to LEFT	**Required Sight Distance to RIGHT**
Roadway Slope to Left 1%	Roadway Slope to Right 1.5%
Left Approach Operating Speed 44mph	Right Approach Operating Speed 40 mph
Required Sight Distance 430 feet	Required Sight Distance 445 feet

Profile Figure



Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) _Y____ List of Obstructions: _None_____________ ___________________________________ ___________________________________ ___________________________________	Clear Sight Distance Right (Y/N) _Y___ List of Obstructions: _None_____________ ___________________________________ ___________________________________ ___________________________________
If the Stopped Driver Eye Position provides clear visibility of the measuring tape at the Roadway Object Position (and all points between that position and the Stopped Driver Eye Position), then visibility is met to the LEFT/RIGHT.	

Site Sketch
Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

EXAMPLE PROBLEM 2: Typical Conditions 2

Question: Does the intersection approach provide clear right turn and left turn sight distance?

Site Characteristics:

- Four-legged approach
- 90 degree intersection angle
- All vertical approaches are less than 2% slope and no vertical curves are present (i.e. level terrain)
- Two-way stop control (minor streets)
- Sidewalks on all approaches
- Crosswalks present at minor street approaches
- Studied approach is the Northbound approach (Southbound approach performed separately)

Comments: For background information on intersection sight distance, please see the ODOT Safety Investigation Manual.

Methodology: After identifying key site characteristics, roadway slope and approach operating speed values are used to determine the required sight distance for each approach. This distance is then measured at the site to determine if the required site distance for right and left turns is provided.

<table>
<tr><th colspan="4">Intersection Sight Distance to the LEFT: Calculated Values</th></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the left alongside the major roadway. At end, place SmartLevel on ground and record slope.</td><td colspan="2">1.5%</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td colspan="2">33 mph (round to 35 mph)</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td colspan="2">335 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td colspan="2">Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>30</td><td colspan="2">290</td><td>335</td></tr>
<tr><td>35</td><td colspan="2">335</td><td>390</td></tr>
<tr><td>40</td><td colspan="2">385</td><td>445</td></tr>
<tr><td colspan="2">Visibility Check</td><td colspan="2">Visibility is provided for entire distance.</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td colspan="2">Yes</td></tr>
</table>

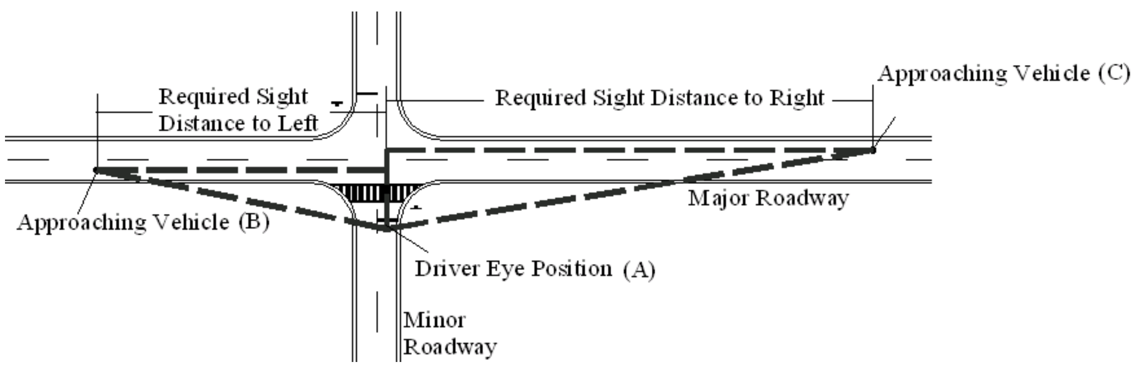
<table>
<tr><th colspan="3">Intersection Sight Distance to the RIGHT: Calculated Values</th></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the right alongside the major roadway. At end, place SmartLevel on ground and record slope..</td><td>2 %</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td>35 mph</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td>390 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td>Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>30</td><td>290</td><td>335</td></tr>
<tr><td>35</td><td>335</td><td>390</td></tr>
<tr><td>40</td><td>385</td><td>445</td></tr>
<tr><td colspan="2">Visibility Check</td><td>Fence is blocking portion of sight triangle</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td>No</td></tr>
</table>

Completed Worksheet:

General Information			
Analyst	Clint Eastwood	Time of Day	4:00 PM
Agency	ODOT	Analysis Year	2008
Date Performed	January 20, 2008	Jurisdiction	Benton County

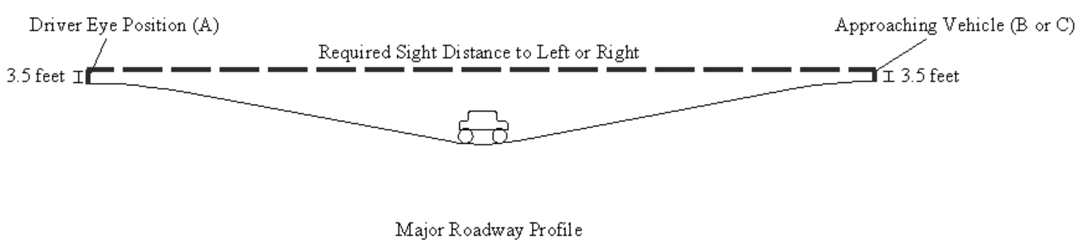
Site Characteristics		**In Office Work**	
Crosswalk at Approach (Y/N)	Y	Horizontal Curve (Y/N)	N
Sidewalk (Y/N)	Y	Approximate Radius (if present)	N/A
Vertical Curve (Y/N)	N		

Plan Figure



Required Sight Distance to LEFT		**Required Sight Distance to RIGHT**	
Roadway Slope to Left	1.5%	Roadway Slope to Right	2%
Left Approach Operating Speed	35 mph	Right Approach Operating Speed	35 mph
Required Sight Distance	335 feet	Required Sight Distance	390 feet

Profile Figure



Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) _Y____ List of Obstructions: _None____________ ___________________________________ ___________________________________ ___________________________________	Clear Sight Distance Right (Y/N) _N___ List of Obstructions: _Obstruction to sight triangle by fence. Check into ownership to have relocated_______________________ ___________________________________
If the Stopped Driver Eye Position provides clear visibility of the measuring tape at the Roadway Object Position (and all points between that position and the Stopped Driver Eye Position), then visibility is met to the LEFT/RIGHT.	

Site Sketch
Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

EXAMPLE PROBLE 3: Horizontal Curve 1

Question: Does the intersection approach provide clear right turn and left turn sight distance?

Site Characteristics:

- Three-legged approach
- 90 degree intersection angle
- All vertical approaches are less than 2% slope and no vertical curves are present (i.e. level terrain)
- One-way stop control (minor street)
- Sidewalks on all approaches
- Crosswalks present at minor street approach
- Studied approach is the Eastbound approach (Westbound approach performed separately)

Comments: For background information on intersection sight distance, please see the ODOT Safety Investigation Manual.

Methodology: After identifying key site characteristics, roadway slope and approach operating speed values are used to determine the required sight distance for each approach. This distance is then measured at the site to determine if the required site distance for right and left turns is provided. For the horizontal curve, measure the approximate radius in office using an aerial photograph.

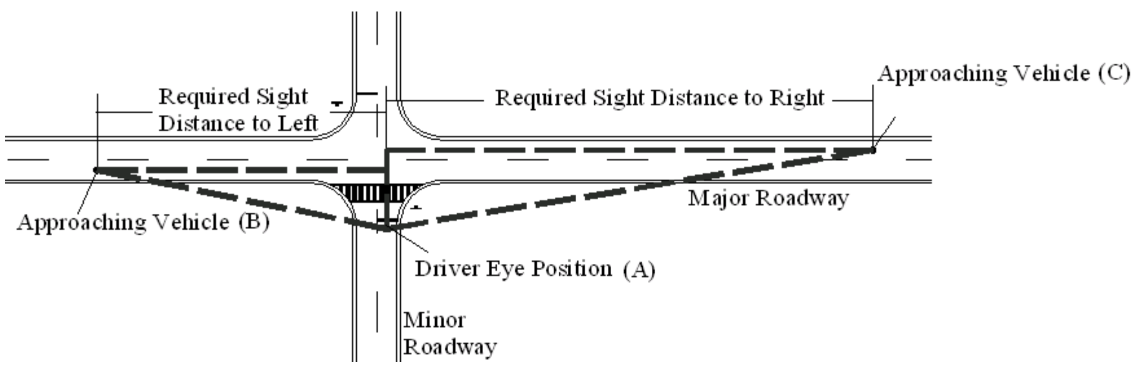
Intersection Sight Distance to the LEFT: Calculated Values		
Roadway Slope: Starting at the driver position, walk 250 feet to the left alongside the major roadway. At end, place SmartLevel on ground and record slope.	2%	
Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.	33 mph (round to 35 mph)	
Required Sight Distance: Using the provided table, look up the required sight distance.	335 feet	
Approach Speed (mph)	Distance to Left (feet)	Distance to Right (feet)
30	290	335
35	**335**	390
40	385	445
Visibility Check	Visibility is provided for entire distance.	
Is Visibility Met?	Yes	

Intersection Sight Distance to the RIGHT: Calculated Values		
Roadway Slope: Starting at the driver position, walk 250 feet to the right alongside the major roadway. At end, place SmartLevel on ground and record slope..	3 %	
Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.	35 mph	
Required Sight Distance: Using the provided table, look up the required sight distance.	390 feet	
Approach Speed (mph)	Distance to Left (feet)	Distance to Right (feet)
30	290	335
35	335	**390**
40	385	445
Visibility Check	Visibility is provided for entire distance.	
Is Visibility Met?	Yes	

Completed Worksheet:

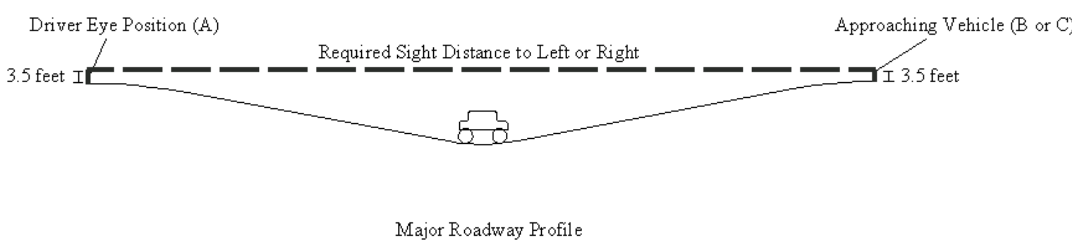
General Information	
Analyst Tom Hanks	Time of Day 3:00 PM
Agency ODOT	Analysis Year 2008
Date Performed January 20, 2008	Jurisdiction Benton County
Site Characteristics	**In Office Work**
Crosswalk at Approach (Y/N) Y	Horizontal Curve (Y/N) Y
Sidewalk (Y/N) Y	Approximate Radius (if present) 730 feet and 790 feet
Vertical Curve (Y/N) N	

Plan Figure



Required Sight Distance to LEFT	**Required Sight Distance to RIGHT**
Roadway Slope to Left 2%	Roadway Slope to Right 3%
Left Approach Operating Speed 35 mph	Right Approach Operating Speed 35 mph
Required Sight Distance 335 feet	Required Sight Distance 390 feet

Profile Figure



Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) _Y____ List of Obstructions: _None___________ _________________________________ _________________________________ _________________________________	Clear Sight Distance Right (Y/N) _Y___ List of Obstructions: _None___________ __________________________________ __________________________________ __________________________________
If the Stopped Driver Eye Position provides clear visibility of the measuring tape at the Roadway Object Position (and all points between that position and the Stopped Driver Eye Position), then visibility is met to the LEFT/RIGHT.	

Site Sketch
Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

EXAMPLE PROBLE 4: Horizontal Curve 2

Question: Does the intersection approach provide clear right turn and left turn sight distance?

Site Characteristics:

- Three-legged approach
- 90 degree intersection angle
- All vertical approaches are less than 2% slope and no vertical curves are present (i.e. level terrain)
- One-way stop control (minor street)
- Sidewalks on all approaches
- Crosswalks present at minor street approach
- Studied approach is the Eastbound approach (Westbound approach performed separately)

Comments: For background information on intersection sight distance, please see the ODOT Safety Investigation Manual.

Methodology: After identifying key site characteristics, roadway slope and approach operating speed values are used to determine the required sight distance for each approach. This distance is then measured at the site to determine if the required site distance for right and left turns is provided. For the horizontal curve, measure the approximate radius in office using an aerial photograph.

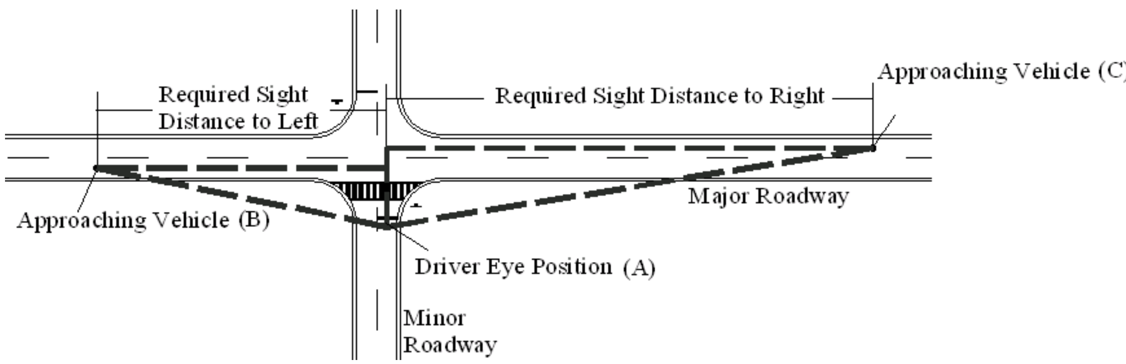
<table>
<tr><td colspan="3">Intersection Sight Distance to the LEFT: Calculated Values</td></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the left alongside the major roadway. At end, place SmartLevel on ground and record slope.</td><td>3%</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td>25 mph</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td>240 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td>Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>20</td><td>195</td><td>225</td></tr>
<tr><td>25</td><td>240</td><td>280</td></tr>
<tr><td>30</td><td>290</td><td>335</td></tr>
<tr><td colspan="2">Visibility Check</td><td>Visibility is provided for entire distance.</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td>Yes</td></tr>
</table>

Intersection Sight Distance to the RIGHT: Calculated Values		
Roadway Slope: Starting at the driver position, walk 250 feet to the right alongside the major roadway. At end, place SmartLevel on ground and record slope..	3 %	
Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.	24 mph (round to 25 mph)	
Required Sight Distance: Using the provided table, look up the required sight distance.	280 feet	
Approach Speed (mph)	Distance to Left (feet)	Distance to Right (feet)
20	195	225
25	240	**280**
30	290	335
Visibility Check	No	
Is Visibility Met?	Presence of shrubs blocks ability to see more than 260 feet down roadway.	

Completed Worksheet:

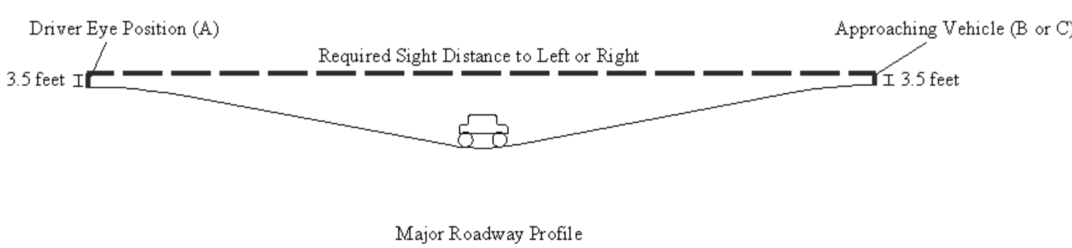
General Information	
Analyst: Meg Ryan	Time of Day: 10:00 AM
Agency: ODOT	Analysis Year: 2008
Date Performed: January 22, 2008	Jurisdiction: Benton County
Site Characteristics	**In Office Work**
Crosswalk at Approach (Y/N): Y	Horizontal Curve (Y/N): Y
Sidewalk (Y/N): Y	Approximate Radius (if present): 425 feet
Vertical Curve (Y/N): N	

Plan Figure



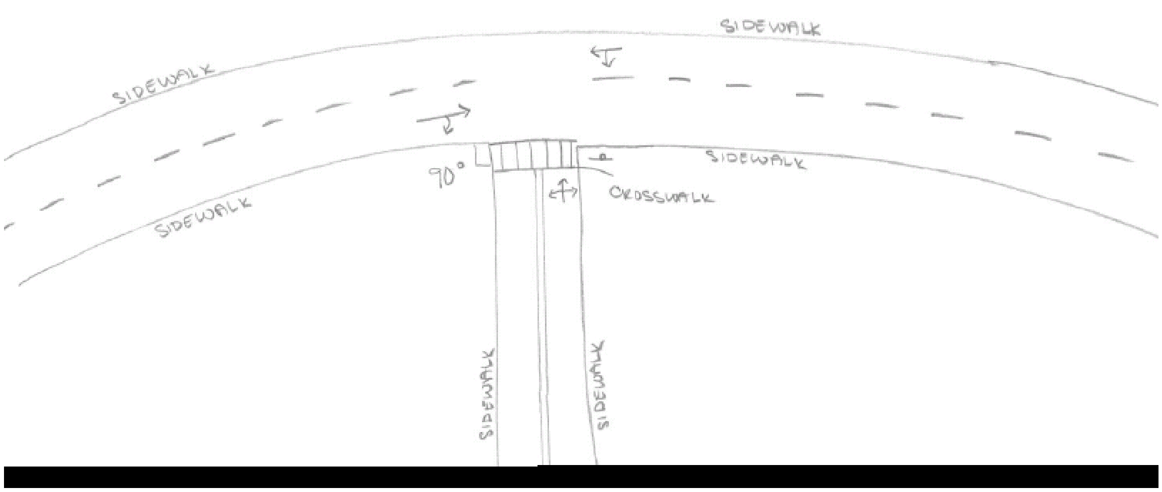
Required Sight Distance to LEFT	**Required Sight Distance to RIGHT**
Roadway Slope to Left: 3%	Roadway Slope to Right: 3%
Left Approach Operating Speed: 25 mph	Right Approach Operating Speed: 25 mph
Required Sight Distance: 240 feet	Required Sight Distance: 280 feet

Profile Figure



Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) _Y____	Clear Sight Distance Right (Y/N) _N___
List of Obstructions: _None____________	List of Obstructions: _Location of shrubbery prevents ability to see more than 260 feet to the right. Look into removal.__
If the Stopped Driver Eye Position provides clear visibility of the measuring tape at the Roadway Object Position (and all points between that position and the Stopped Driver Eye Position), then visibility is met to the LEFT/RIGHT.	

Site Sketch



Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

EXAMPLE PROBLEM 5: Vertical Curve

Question: Does the intersection approach provide clear right turn and left turn sight distance?

Site Characteristics:

- Four-legged approach
- 90 degree intersection angle
- Two-way stop control (minor streets)
- Sidewalks on all approaches
- Crosswalks present at minor street approaches
- Studied approach is the Southbound approach (Northbound approach performed separately)

Comments: For background information on intersection sight distance, please see the ODOT Safety Investigation Manual.

Methodology: After identifying key site characteristics, roadway slope and approach operating speed values are used to determine the required sight distance for each approach. This distance is then measured at the site to determine if the required site distance for right and left turns is provided.

<table>
<tr><th colspan="4">Intersection Sight Distance to the LEFT: Calculated Values</th></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the left alongside the major roadway. At end, place SmartLevel on ground and record slope.</td><td colspan="2">3%</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td colspan="2">35 mph</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td colspan="2">335 feet</td></tr>
<tr><td>Approach Speed (mph)</td><td colspan="2">Distance to Left (feet)</td><td>Distance to Right (feet)</td></tr>
<tr><td>30</td><td colspan="2">290</td><td>335</td></tr>
<tr><td>35</td><td colspan="2">335</td><td>390</td></tr>
<tr><td>40</td><td colspan="2">385</td><td>445</td></tr>
<tr><td colspan="2">Visibility Check</td><td colspan="2">Visibility is provided for entire distance.</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td colspan="2">Yes</td></tr>
</table>

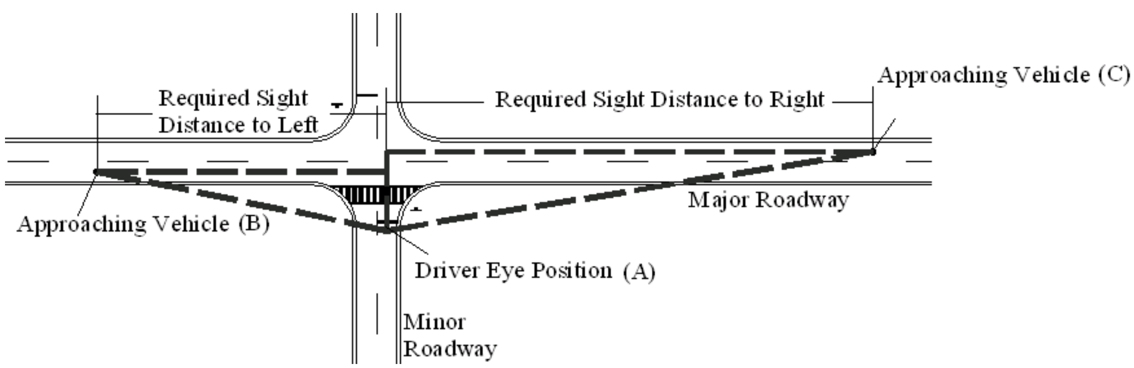
<table>
<tr><td colspan="4">Intersection Sight Distance to the RIGHT: Calculated Values</td></tr>
<tr><td colspan="2">Roadway Slope: Starting at the driver position, walk 250 feet to the right alongside the major roadway. At end, place SmartLevel on ground and record slope..</td><td colspan="2">- 6 %</td></tr>
<tr><td colspan="2">Approach Speed: Remaining 250 feet away, measure vehicle speeds. Use procedures in speed study section of ODOT Safety Investigation Manual.</td><td colspan="2">35 mph</td></tr>
<tr><td colspan="2">Required Sight Distance: Using the provided table, look up the required sight distance.</td><td colspan="2">333 feet</td></tr>
<tr><td rowspan="2">Approach Speed (mph)</td><td colspan="3">Downgrades</td></tr>
<tr><td>3%</td><td>6%</td><td>9%</td></tr>
<tr><td>30</td><td>257</td><td>271</td><td>287</td></tr>
<tr><td>35</td><td>315</td><td>333</td><td>354</td></tr>
<tr><td>40</td><td>378</td><td>400</td><td>427</td></tr>
<tr><td colspan="2">Visibility Check</td><td colspan="2">No</td></tr>
<tr><td colspan="2">Is Visibility Met?</td><td colspan="2">Assuming a car height of 4.5 feet, the sag curve to the right limits visibility of cars more than 75 feet away from intersection.</td></tr>
</table>

Completed Worksheet:

General Information			
Analyst	Richard Gere	Time of Day	1:00 PM
Agency	ODOT	Analysis Year	2008
Date Performed	January 22, 2008	Jurisdiction	Benton County

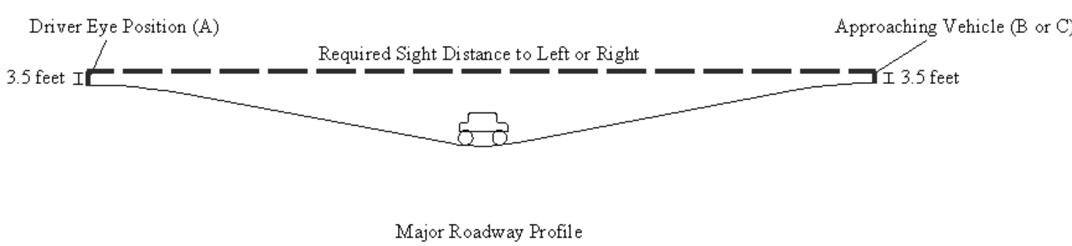
Site Characteristics		**In Office Work**	
Crosswalk at Approach (Y/N)	Y	Horizontal Curve (Y/N)	N
Sidewalk (Y/N)	Y	Approximate Radius (if present)	N/A
Vertical Curve (Y/N)	Y		

Plan Figure



Required Sight Distance to LEFT		**Required Sight Distance to RIGHT**	
Roadway Slope to Left	3%	Roadway Slope to Right	- 6%
Left Approach Operating Speed	35 mph	Right Approach Operating Speed	35 mph
Required Sight Distance	335 feet	Required Sight Distance	333 feet

Profile Figure



Visibility LEFT	**Visibility RIGHT**
Clear Sight Distance Left (Y/N) _Y____ List of Obstructions: _None___________ ___________________________________ ___________________________________ ___________________________________	Clear Sight Distance Right (Y/N) _N___ List of Obstructions: _ Assuming a car height of 4.5 feet, the sag curve to the right limits visibility of cars more than 75 feet away from intersection. _______________
If the Stopped Driver Eye Position provides clear visibility of the measuring tape at the Roadway Object Position (and all points between that position and the Stopped Driver Eye Position), then visibility is met to the LEFT/RIGHT.	

Site Sketch
Include: lanes, crosswalks, sidewalks, horizontal curves, vehicle movements, etc.

Decision/Dilemma Zone Package

Decision/Dilemma Zones

Decision and dilemma zones are often used interchangeably, when in fact they represent two very different scenarios. Decision and dilemma zones are used to qualify the situation drivers are faced when approaching an intersection during its yellow phase. A decision zone is present if drivers approaching the intersection are able to recognize the yellow phases and decide whether to stop before reaching the intersection or continue on at their approach speed and pass through the intersection before the conflicting movement receives their green time. Both of these maneuvers must be able to be executed safely. In order for this to happen, the yellow and/or yellow plus all red interval(s) need to be long enough to allow a driver to decide to either enter and clear the intersection when they are far enough back from it to still have enough room available for required stopping sight distance.

In contrast, a dilemma zone occurs when the driver approaching the intersection sees the yellow phase begin and has neither enough time to safely clear the intersection nor enough room to safely stop before entering it. It is referred to as a dilemma zone because either option is dangerous to the passengers in the car and creates a dilemma for the drivers. The presence of a dilemma zone indicates an engineering design error that should be taken quite seriously.

The presence of dilemma zones, which are obviously dangerous, can result in an overrepresentation of crashes at intersections. Drivers who attempt to stop before entering the intersection run the risk of being rear-ended by other vehicles or skidding into roadside objects. Those drivers who attempt to clear the intersection when insufficient time is provided can be involved in right-angle crashes between themselves and conflicting movements that just received their green time.

DECISION/DILEMMA ZONE WORKSHEET
YELLOW AND ALL RED PHASING

Decision Zone: A decision zone is present if the driver is able to see the yellow phase of the signal at a location where they decide to either stop before the light or continue through the light safely.
Dilemma Zone: A dilemma zone is present if when the light turns yellow the driver can neither stop before the light or safety pass through the intersection. This indicates an engineering design error.

General Information	
Analyst ___________________	Time of Day ____________________
Agency ___________________	Analysis Year ____________________
Date Performed ___________________	Jurisdiction ____________________
Site Characteristics	**Assumptions**
Intersection Width (ft) ________	Standard Car Length (ft) ________
Yellow Time (s) ________	Perception/Reaction Time (s) ________
Red Time (s) ________	
Approach Speed (mph) ________	
Approach Slope (%) ________	
Distance Traveled During Yellow Time	
Yellow Distance = (Yellow Time)*(Approach Speed)*(5280/3600)	
Yellow Distance (ft) ____________	
Distance Traveled During Red Time	
Red Distance = (Red Time)*(Approach Speed)*(5280/3600)	
Red Distance (ft) ____________	
Note: If signal does not include an all red interval, assume a Red Distance of zero.	

Required Stopping Sight Distance (SSD)

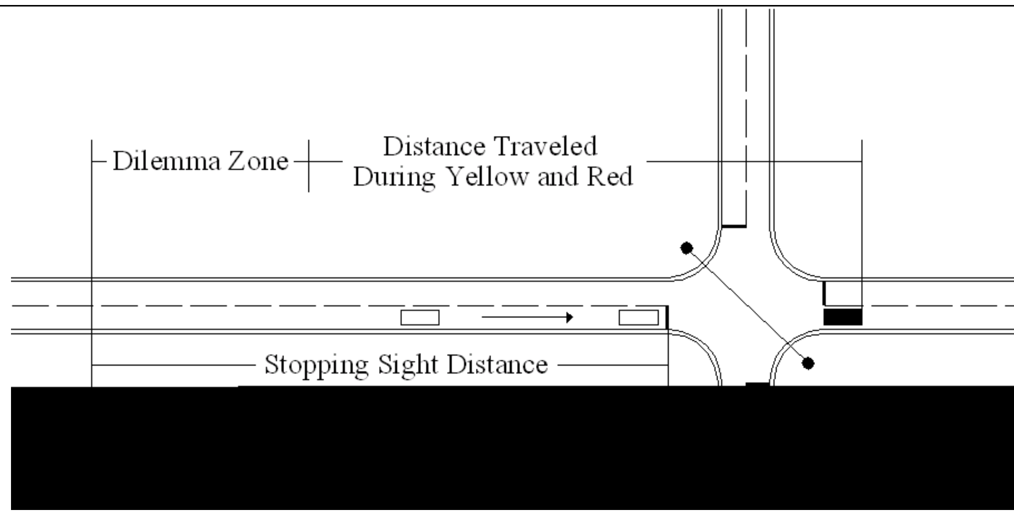
SSD = (Perception/Reaction Time)*(Approach Speed)(5280/3600)

$$+ \frac{\text{(Approach Speed)}^2}{(30)*[0.348 +/- (\text{Grade}/100)]}$$

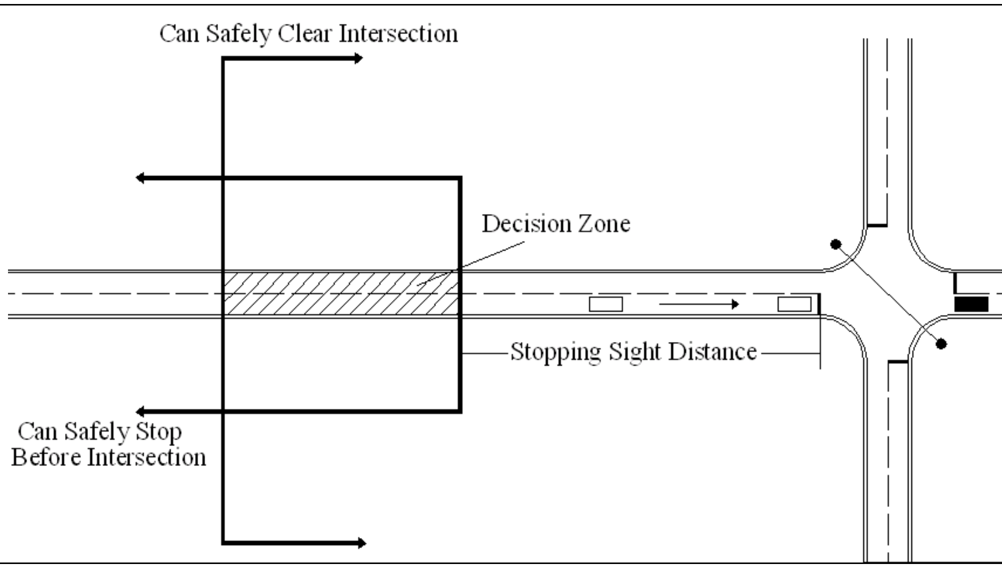
Note: Use + for Grade/100 for uphill approaches and – for Grade/100 for downhill approaches

SSD (ft) _____________

Plan View: Dilemma Zone



Plan View: Decision Zone



Dilemma Zone Calculation
A: [(Yellow Distance) + (Red Distance)] – [(Standard Car Length)+(Intersection Width)] = ____________ ft B: SSD = _________ ft If B is larger than A, a Dilemma Zone is present. If B is less than A, Decision Zone is present. **Is a Dilemma Zone Present? ______________** Dilemma Zone Distance (if applicable) = B – A Dilemma Zone Distance (ft): ____________ **Is a Decision Zone Present? ______________** Decision Zone Distance (if applicable) = A – B Decision Zone Distance (ft): ____________

DECISION/DILEMMA ZONE WORKSHEET
YELLOW AND ALL RED PHASING

Decision Zone: A decision zone is present if the driver is able to see the yellow phase of the signal at a location where they decide to either stop before the light or continue through the light safely.
Dilemma Zone: A dilemma zone is present if when the light turns yellow the driver can neither stop before the light or safety pass through the intersection. This indicates an engineering design error.

General Information			
Analyst	Angelia Jolie________	Time of Day	4:00 PM_____________
Agency	ODOT_____________	Analysis Year	2008_______________
Date Performed	April 2____________	Jurisdiction	Linn County_________
Site Characteristics		**Assumptions**	
Intersection Width (ft)	36______	Standard Car Length (ft)	20______
Yellow Time (s)	4_______	Perception/Reaction Time (s)	1_______
Red Time (s)	0_______		
Approach Speed (mph)	35______		
Approach Slope (%)	level____		

Distance Traveled During Yellow Time

Yellow Distance = (Yellow Time)*(Approach Speed)*(5280/3600)
(4)*(35)*(5280/3600) = 205.33 ft
Round down to 205 ft to be conservative

Yellow Distance (ft) 205_________

Distance Traveled During Red Time

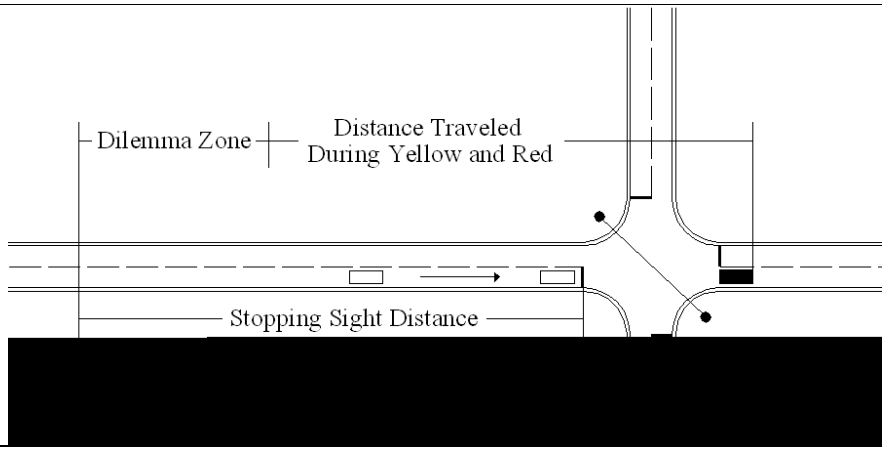
Red Distance = (Red Time)*(Approach Speed)*(5280/3600)
No red distance
Red Distance (ft) 0___________
Note: If signal does not include an all red interval, assume a Red Distance of zero.

Required Stopping Sight Distance (SSD)

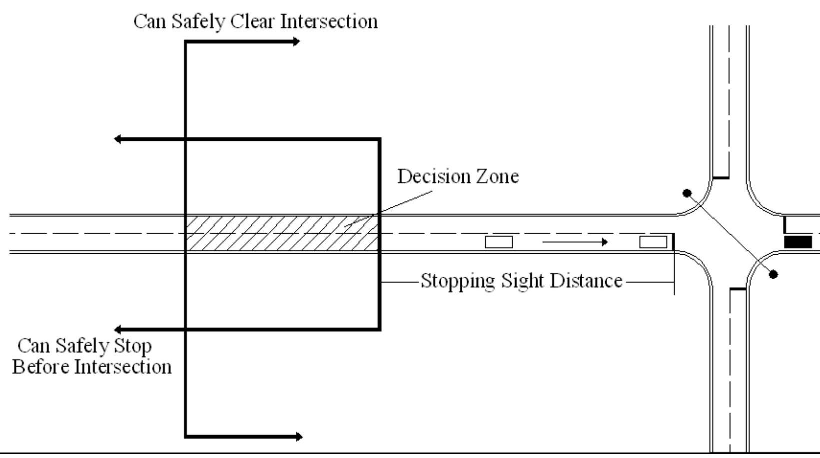
$$SSD = (\text{Perception/Reaction Time})*(\text{Approach Speed})(5280/3600) + \frac{(\text{Approach Speed})^2}{(30)*[0.348 +/- (\text{Grade}/100)]}$$

Note: Use + for Grade/100 for uphill approaches and – for Grade/100 for downhill approaches
(1)*(35)(5280/3600) + [(35)^2]/[(30)*(0.348)] = 168.67
Round up to 170 to be conservative
SSD (ft) 170__________

Plan View: Dilemma Zone



Plan View: Decision Zone



Dilemma Zone Calculation

A: [(Yellow Distance) + (Red Distance)] – [(Standard Car Length)+(Intersection Width)]
= 149_______ ft
[(205)+(0)] – [(20) + (36)] = 149

B: SSD = 170_______ ft

B = 170 > A = 149

If B is larger than A, a Dilemma Zone is present.

If B is less than A, Decision Zone is present.

Is a Dilemma Zone Present? YES___________

Dilemma Zone Distance (if applicable) = B – A

(170) – (149) = 21

Dilemma Zone Distance (ft): 21__________

Is a Decision Zone Present? NO___________

Decision Zone Distance (if applicable) = A – B

Decision Zone Distance (ft): ____________

DECISION/DILEMMA ZONE WORKSHEET
YELLOW AND ALL RED PHASING

Decision Zone: A decision zone is present if the driver is able to see the yellow phase of the signal at a location where they decide to either stop before the light or continue through the light safely.
Dilemma Zone: A dilemma zone is present if when the light turns yellow the driver can neither stop before the light or safety pass through the intersection. This indicates an engineering design error.

General Information

Analyst	Jennifer Aniston	Time of Day	5:00 PM
Agency	ODOT	Analysis Year	2008
Date Performed	April 2	Jurisdiction	Linn Benton

Site Characteristics		**Assumptions**	
Intersection Width (ft)	36	Standard Car Length (ft)	20
Yellow Time (s)	6	Perception/Reaction Time (s)	1
Red Time (s)	0		
Approach Speed (mph)	35		
Approach Slope (%)	level		

Distance Traveled During Yellow Time

Yellow Distance = (Yellow Time)*(Approach Speed)*(5280/3600)
(6)*(35)*(5280/3600) = 308

Yellow Distance (ft) 308

Distance Traveled During Red Time

Red Distance = (Red Time)*(Approach Speed)*(5280/3600)
No Red Distance
Red Distance (ft) 0
Note: If signal does not include an all red interval, assume a Red Distance of zero.

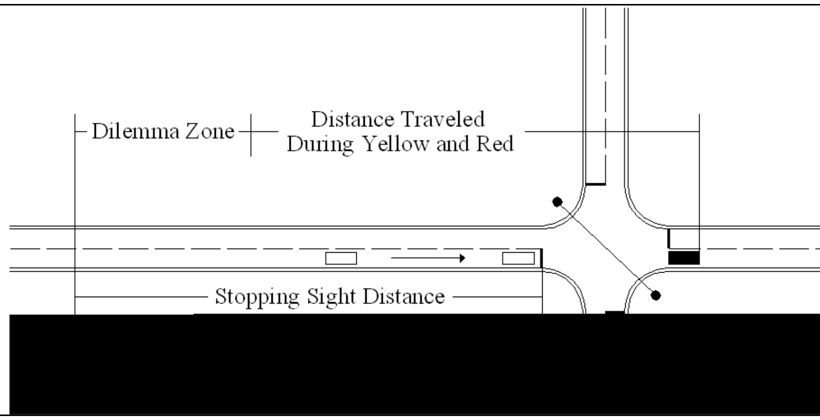
Required Stopping Sight Distance (SSD)

$$\text{SSD} = (\text{Perception/Reaction Time})*(\text{Approach Speed})(5280/3600) + \frac{(\text{Approach Speed})\text{^}2}{(30)*[0.348 +/- (\text{Grade}/100)]}$$

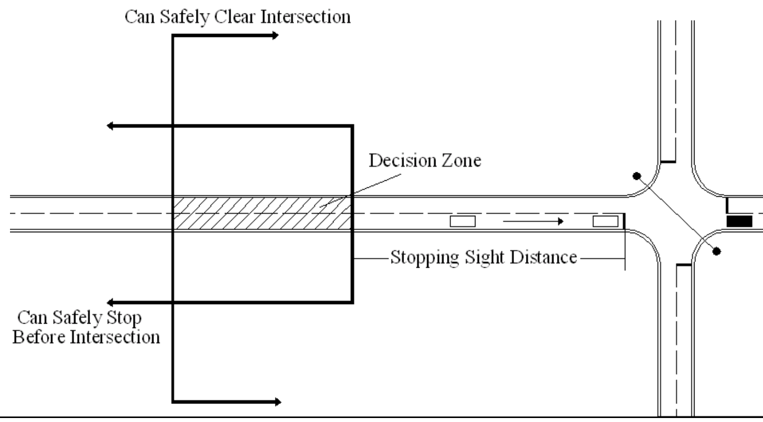
Note: Use + for Grade/100 for uphill approaches and – for Grade/100 for downhill approaches
(1)*(35)*(5280/3600) + [(35)^2]/[(30)*(0.348)] = 168.67
Round up to 170 to be conservative

SSD (ft) 170

Plan View: Dilemma Zone



Plan View: Decision Zone



Dilemma Zone Calculation

A: [(Yellow Distance) + (Red Distance)] – [(Standard Car Length)+(Intersection Width)]
= 252__________ ft
[(308) + (0)] – [(20) + (36)] = 252

B: SSD = 170______ ft
B = 170 < A = 252
If B is larger than A, a Dilemma Zone is present.
If B is less than A, Decision Zone is present.

Is a Dilemma Zone Present? NO____________

Dilemma Zone Distance (if applicable) = B – A

Dilemma Zone Distance (ft): ____________

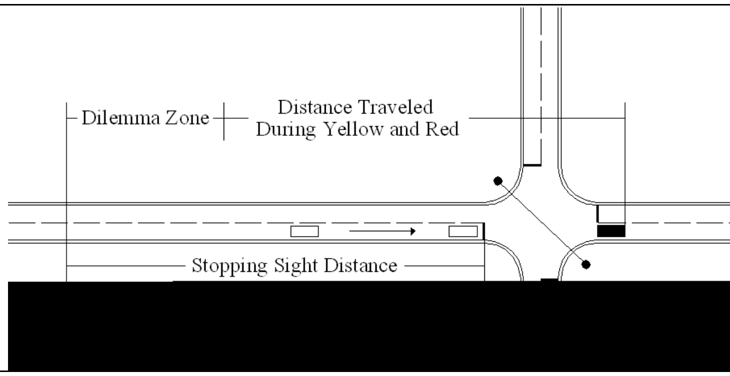
Is a Decision Zone Present? YES___________

Decision Zone Distance (if applicable) = A – B
(252) – (170) = 82
Decision Zone Distance (ft): 82___________

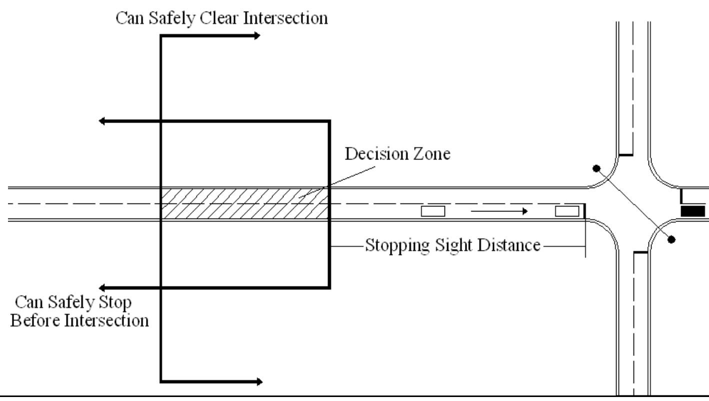
YELLOW AND ALL RED PHASING

Decision Zone: A decision zone is present if the driver is able to see the yellow phase of the signal at a location where they decide to either stop before the light or continue through the light safely.
Dilemma Zone: A dilemma zone is present if when the light turns yellow the driver can neither stop before the light or safety pass through the intersection. This indicates an engineering design error.

General Information	
Analyst: Brad Pitt Agency: ODOT Date Performed: April 2	Time of Day: 5:45 PM Analysis Year: 2008 Jurisdiction: Linn Benton
Site Characteristics	**Assumptions**
Intersection Width (ft): 24 Yellow Time (s): 3 Red Time (s): 2 Approach Speed (mph): 25 Approach Slope (%): level	Standard Car Length (ft): 20 Perception/Reaction Time (s): 1
Distance Traveled During Yellow Time	
Yellow Distance = (Yellow Time)*(Approach Speed)*(5280/3600) (3)*(25)*(5280/3600) = 110 Yellow Distance (ft) 110	
Distance Traveled During Red Time	
Red Distance = (Red Time)*(Approach Speed)*(5280/3600) (2)*(25)*(5280/3600) = 73.33 Round down to 73 to be conservative Red Distance (ft) 73 Note: If signal does not include an all red interval, assume a Red Distance of zero.	
Required Stopping Sight Distance (SSD)	
SSD = (Perception/Reaction Time)*(Approach Speed)(5280/3600) + (Approach Speed)^2 / (30)*[0.348 +/- (Grade/100)] Note: Use + for Grade/100 for uphill approaches and – for Grade/100 for downhill approaches (1)*(25)*(5280/3600) + [(25)^2]/[(30)*(0.348)] = 96.53 Round up to 100 to be conservative SSD (ft) 100	
Plan View: Dilemma Zone	



Plan View: Decision Zone



Dilemma Zone Calculation

A: [(Yellow Distance) + (Red Distance)] – [(Standard Car Length)+(Intersection Width)]
= 139__________ ft
[(110) + (73)] – [(20) + (24)] = 139

B: SSD = 100______ ft
B = 100 < A = 139
If B is larger than A, a Dilemma Zone is present.
If B is less than A, Decision Zone is present.

Is a Dilemma Zone Present? NO____________

Dilemma Zone Distance (if applicable) = B – A

Dilemma Zone Distance (ft): ____________

Is a Decision Zone Present? YES___________

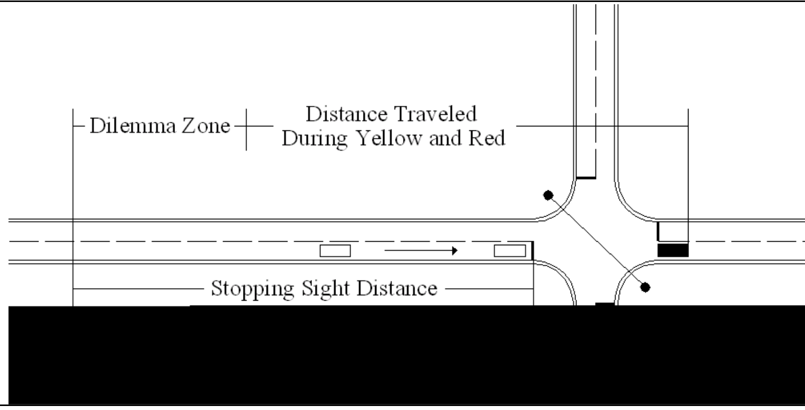
Decision Zone Distance (if applicable) = A – B
(139) – (100) = 39
Decision Zone Distance (ft): 39___________

YELLOW AND ALL RED PHASING

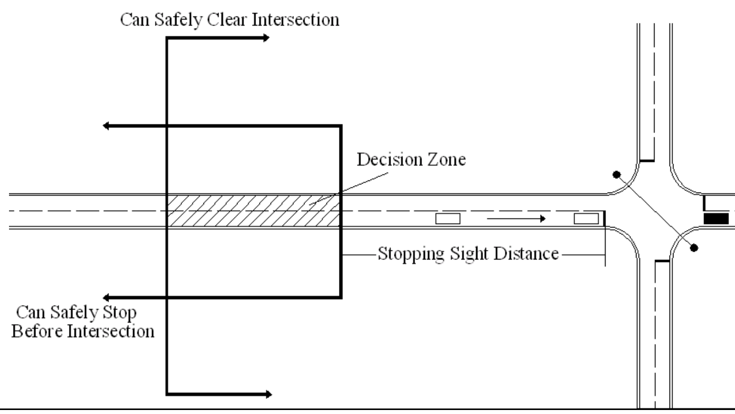
Decision Zone: A decision zone is present if the driver is able to see the yellow phase of the signal at a location where they decide to either stop before the light or continue through the light safely.
Dilemma Zone: A dilemma zone is present if when the light turns yellow the driver can neither stop before the light or safety pass through the intersection. This indicates an engineering design error.

General Information	
Analyst: Michael Douglas Agency: ODOT Date Performed: April 2	Time of Day: 5:30 PM Analysis Year: 2008 Jurisdiction: Linn Benton
Site Characteristics	**Assumptions**
Intersection Width (ft): 24 Yellow Time (s): 2 Red Time (s): 1 Approach Speed (mph): 25 Approach Slope (%): level	Standard Car Length (ft): 20 Perception/Reaction Time (s): 1
Distance Traveled During Yellow Time	
Yellow Distance = (Yellow Time)*(Approach Speed)*(5280/3600) (2)*(25)*(5280/3600) = 73.33 Round down to 73 to be conservative Yellow Distance (ft) 73	
Distance Traveled During Red Time	
Red Distance = (Red Time)*(Approach Speed)*(5280/3600) (1)*(25)*(5280/3600) = 36.67 Round down to 36 to be conservative Red Distance (ft) 36 Note: If signal does not include an all red interval, assume a Red Distance of zero.	
Required Stopping Sight Distance (SSD)	
SSD = (Perception/Reaction Time)*(Approach Speed)(5280/3600) + $\frac{\text{(Approach Speed)}^\wedge 2}{(30)*[0.348 +/- (Grade/100)]}$ Note: Use + for Grade/100 for uphill approaches and – for Grade/100 for downhill approaches (1)*(25)*(5280/3600) + [(25)^2]/[(30)*(0.348)] = 96.53 Round up to 100 to be conservative SSD (ft) 100	

Plan View: Dilemma Zone



Plan View: Decision Zone



Dilemma Zone Calculation

A: [(Yellow Distance) + (Red Distance)] – [(Standard Car Length)+(Intersection Width)]
= 65___________ ft

[(73) + (36)] – [(20) + (24)] = 65

B: SSD = 100______ ft

B = 100 > A = 65

If B is larger than A, a Dilemma Zone is present.

If B is less than A, Decision Zone is present.

Is a Dilemma Zone Present? YES___________

Dilemma Zone Distance (if applicable) = B – A

(100) – (65) = 35

Dilemma Zone Distance (ft): 35__________

Is a Decision Zone Present? NO___________

Decision Zone Distance (if applicable) = A – B

Decision Zone Distance (ft): _____________