

Safety Audits: A Comparison of Traditional Safety Audits to the Interactive Highway

Safety Design Model

by

Tegan Marie Houghton

A PROJECT

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In the United States there are currently two different options for providing safety audits to roadway projects. Traditional audits can be conducted using procedures similar to those in the United Kingdom, or those similar to Australia and New Zealand (Austroads). Another option for conducting safety audits is to use the Interactive Highway Safety Design Model (IHSDM) developed by the Federal Highway Administration. Traditional audits are comprised of an independent audit team, which performs in depth evaluations of projects at different stages of development and indicates potential areas of safety concern. The IHSDM uses policy review, crash prediction, design consistency, intersection review, and traffic analysis modules to evaluate project design safety. Although the traditional safety audit methods provide a more catered look at the project design, the IHSDM is more applicable for use in the United States. The IHSDM is able to reach nearly the same level of detail as the traditional safety audits, provided that some follow-up analysis is performed outside of the Model itself, with less requirements for manpower and funding. Endorsement of its use will allow wider application of safety audits than endorsement of traditional safety audits, which in turn expands the use and benefits of safety applications in the United States.

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Dr. Karen K. Dixon

Key Words: Safety Audits, Interactive Highway Safety Design Model (IHSDM),
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Tegan Marie Houghton, Author

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TABLE OF CONTENTS

Chapter 1: Introduction	1
Chapter 2: Safety Audits	1
2.1: Background on Use.....	1
2.2: Benefits of Use.....	2
Chapter 3: The Safety Audit Team	4
3.1: United Kingdom Approach.....	4
3.2: AUSTRROADS Approach.....	5
3.3: Specialties Involved.....	6
Chapter 4: When to Perform a Safety Audit.....	8
4.1: What Stage of Project Development.....	8
4.2: Which Projects Should be Audited.....	10
Chapter 5: Development of a Traditional Safety Audit.....	11
Chapter 6: Limitations of Traditional Safety Audit Methods.....	17
Chapter 7: Safety Audit Software Packages	19
7.1: Background on IHSDM.....	19
7.2: Crash Prediction Module	20
7.3: Design Consistency Module	21
7.4: Driver and Vehicle Module	22
7.5: Intersection Review Module.....	22
7.6: Policy Review Module.....	23
7.7: Traffic Analysis Module.....	24
Chapter 8: Limitations of Safety Audit Software	26
Chapter 9: Conclusions.....	29
Bibliography	37
Appendix A.....	38

LIST OF TABLES

Table 1: Traditional Safety Audit Checklist	13
Table 2: Traditional Safety Audit Checklist (continued).....	14
Table 3: Crash Analysis Elements Used in Analysis by IHSDM.....	20
Table 4: Policy Review Elements Used in Analysis by IHSDM.....	24
Table 5: Evaluation of Previously Discussed Benefits.....	34

LIST OF APPENDIX TABLES

Table A- 1: High Crash Location Identification Technique Usage in the U.S. (1982)	87
Table A- 2: High Crash Location Identification Technique Usage in the U. K. (1984)...	88
Table A- 3: Recommended Values of Analysis Periods.....	92
Table A- 4: Operations Based Studies from FHWA (1981).....	102
Table A- 5: Environmental Studies from FHWA (1981)	103
Table A- 6: Additional Studies from FHWA (1981).....	104

Chapter 1: Introduction

With the development of the Highway Safety Manual by the Federal Highway Association (FHWA) and a safety manual for use by the Oregon Department of Transportation (ODOT), the issue of safe highway design is becoming more and more prevalent in today's world. One way to help ensure that a transportation design project is safe before it is opened to users is to provide a safety audit. Safety audits are designed to identify deficiencies in design and provide additional measures that can be taken to provide the safest environment to all facility users. Two methods are currently available for projects of agencies interested in participating in a safety audit. The first method is to perform a traditional safety audit, which has been done by the United Kingdom as well as New Zealand and Australia since the late 1900's. This method involves performing safety audits with a qualified independent group of analysts. More recently, another tool has been developed by the FHWA called the Interactive Highway Safety Design Model (IHSDM), which performs safety audits using software packaging and inputs from other design tools. In the following chapters, this thesis will provide background information on traditional safety audits and IHSDM software, limitations of each of their uses, and a recommendation on which method is most suitable for use in the United States.

Chapter 2: 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" (TRB, 2004, pg 3). The goal of the safety audit is to find safety deficiencies of a roadway design and correct them to prevent future injury. This can be as preliminary as an evaluation of planning phases and as final as inspection of constructed facility. 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 (TRB, 2004, pg 3). In the early 1990's, these practices were also implemented in Australia and New Zealand (TRB, 2004, pg 3). It was not until 1996 that roadway safety audits were first introduced in the United States (TRB, 2004, pg 1). Based on this timeline, it would make sense that the United Kingdom, Australia, and New Zealand would be more advanced in their practicing of safety audits. Therefore, when evaluating safety audit methods, the policies of the United Kingdom and Australia and New Zealand make for good background on standard procedures.

2.2: Benefits of Use

Several benefits have been identified from the use of road safety audits. Both Austroads (2002) and TRB (2004) have pointed out that safety audits create a greater prominence of safety during the overall design process. During design there are multiple factors to keep track of, and incorporating the use of safety audits will encourage engineers to actively consider safety parameters throughout the design stages. TRB (2004) has also pointed out that safety audits provide a good opportunity for people who are well versed in safety practices to provide feedback to engineers on their current practices. This can be either validation of current performance or highlighting areas that need more focus.

Safety audits have also shown potential to reduce the overall number of crashes experienced at a location, as well as the severity of crashes (Austroads, 2002). According to K.W. Ogden (1996), studies in the United Kingdom have shown that safety audits have the potential to remove up to one-third of the total future crashes. Safety audits also reduce the need for future remedial work (Austroads, 2002). This is important because it is less expensive to change design plans than to reconstruct existing roadways. Also, safety audits are able to yield significant accident savings while generally using less than 0.5% of the total cost of the project (PIARC, 2003). For more information on savings due to crash reductions, please see Chapter 11 of the Appendix.

Another benefit of safety audits, identified by TRB (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 a voice in the design process (TRB, 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: The Safety Audit Team

One of the first steps to performing a traditional safety audit is to compile the audit team. The audit team is the group of individuals (and their specialties) that will be evaluating the project design to ensure adequate safety has been provided. Therefore, 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: United Kingdom Approach

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

The team leader of each safety audit team is required to have a minimum of four years experience in either safety analysis or crash investigations, and at least two days of continued education in safety audit procedures, crash investigation, or general safety practices (TRB, 2004). The team leader is also required to have finished five safety audits during the past twelve months (TRB, 2004).

Becoming a team member requires less experience than becoming a team leader, but it is still quite a lot to accomplish. The United Kingdom recommends that a team member have a minimum of two years experience in safety analysis or crash investigations (TRB,

2004). They also require a minimum of two days of continued education in safety audit practices, crash investigation, or general safety (TRB, 2004). Finally, the United Kingdom expects all team members to have completed at least five safety audits in the past 24 months, for a minimum of ten days experience in audit production (TRB, 2004). Team members can participate in these five audits as either team members, team leaders, or observers (TRB, 2004).

Two additional contributors to the safety audit team are the observer and the specialist. It is recommended that the observer have a minimum of one year's worth of experience and ten days of training in safety audit procedures, safety analysis, and/or crash investigation (TRB, 2004). According to the TRB (2004) study, the primary goal of the observer is to assist in the audit process and gain knowledge in the procedure (so he or she can eventually becoming a team member).

The specialist is to serve as an outside resource to the audit team. This person is not technically a member of the group but instead provides expertise in a specific area on an as needed basis (TRB, 2004).

3.2: AUSTROADS Approach

Austrroads (2002) has identified two different classifications for audit team members in New Zealand and Australia: team leader and team member. According to Austrroads (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.

A Senior Road Safety Auditor is required to have completed a minimum of a two day, recognized training program in auditing (Austroads, 2002). Senior Road Safety Auditors must also have a minimum of five years experience in road design, construction, or traffic engineering (as applicable to each type of project), and have contributed to at least five audits (three of which must have been conducted in the design stage). Finally, one of these five audits needs to have been conducted in the past year, which Austroads (2002) specifies is to help keep the auditor's experience current.

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 learn about auditing procedures.

3.3: Specialties Involved

A 'core team', which includes a safety analyst, roadway designer, and traffic engineer, should typically be used for each audited project, according to the TRB (2004) study. TRB (2004) points out that other team members can be added to this core, depending on

the demands of the project, which 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.

Chapter 4: When to Perform a Safety Audit

Many stages have been identified as useful ones for conducting traditional safety audits. These include the planning, preliminary design, final design, traffic control device construction planning, construction, and construction completion stages. The following sections summarize these different auditing stages and which projects should be considered for auditing.

4.1: What Stage of Project Development

Planning

Austroads (2002) and the TRB (2004) study identify the planning stage as a potential stage for a safety audit. According to TRB (2004), things evaluated during the planning stage include: project scope, alignment location and preliminary layout, intersection designations, access spacing and control, projected impact on surrounding land use and infrastructure, etc.

Preliminary Design

The preliminary design period is also a stage for analysis identified by the TRB (2004) study and Austroads (2002). According to TRB (2004), this is a required audit stage for the United Kingdom. This is the audit stage where the project is evaluated for compliance with relevant design standards (TRB, 2004). Areas evaluated include: horizontal and vertical alignment, intersection layout, sight distance, typical section widths, use of superelevation, multimodal factors, and human factors (TRB, 2004).

Final Design

The final design stage of a project development is also a safety audit analysis stage that is identified by TRB (2004) and Austroads (2002). This stage is also required for auditing in the United Kingdom (TRB, 2004). A safety audit at this stage would include attention to the final geometrics, signing and striping plans, lighting plans, landscaping, detailed layout of intersections/interchanges, drainage plans, roadside objects, etc (TRB, 2004).

Traffic Control Device (TCD) Construction Planning

The TCD stage is outlined by TRB (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 (TRB, 2004).

Construction Stage

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

Construction Completion

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

4.2: Which Projects Should be Audited

Austrroads (2002) has identified three ways of determining which projects should be audited. The first option is to require a percentage of all projects on major roadways to be audited. The second option is to require all projects over a certain project cost threshold to be audited. Third, an agency can require a certain percentage of all projects over a project cost threshold be audited. According to TRB (2004), New Zealand has chosen to allow agencies to require all projects within their jurisdiction to be audited, unless it is determined unnecessary. As TRB (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 (TRB, 2004). According to TRB (2004), they also require that all projects that have had a road safety audit participate in a road safety audit monitoring process, which evaluates 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” (TRB, 2004, pg 21).

Chapter 5: Development of a Traditional Safety Audit

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 to creating a safety audit, identified by Austroads (2002), is to select an appropriate audit team for the project. This is the first step in the audit process identified by the TRB (2004) study. The audit team size and expertise will vary based on the 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 TRB (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. (TRB, 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 to date and justification, land use information, environmental concerns (i.e. historic buildings or endangered species), and any

documents from previous road safety audits for the site. Both TRB (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 TRB (2004) as the next step, and is 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 (TRB, 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 NCHRP, 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. TRB (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
<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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
<ul style="list-style-type: none"> • Adjacent Land Use • Pedestrian Requirements • Bicycle Requirements • Motorcycle Requirements • Equestrian Requirements (if applicable) • Truck Requirements • Public Transportation Aspects • Elderly Pedestrians • Disabled Pedestrians 	<ul style="list-style-type: none"> • Overtaking • Merges • Rest Areas • Pull-Outs • Medians • Clearzone • Crash Barriers • Operations • Temporary Traffic Control • Signal Considerations • Signal Display 	<ul style="list-style-type: none"> • Horizontal Geometry • Vertical Geometry • Sight Distance • Roadway Tie-In Locations • Driver Expectancy • Bridge Treatments • Culvert Placement 	<ul style="list-style-type: none"> • Roadway Lighting • Sign Requirements • Roadway Markings • Roadway Delineations • Detours • Roadway Ponding

Step 6: Final Report

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 (TRB, 2004). According to TRB (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 TRB (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. They say that discussing before hand 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” (TRB, 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). TRB (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 TRB (2004) and Austroads (2002) have identified that the project team should respond to the conclusions. These responses should be in written form and convey whether the suggested problems have been mitigated (TRB, 2004). In the event that they are not being addressed in the design, justification should be provided as to why the project team is choosing not to change their design (TRB, 2004).

Step 9: Implement Mitigations

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

Chapter 6: Limitations of Traditional Safety Audit Methods

There are several limitations associated with traditional safety audit methods. These perceived limitations have led agencies to look for other means of performing safety audits. The first of these limitations is manpower. As discussed in Chapter 3, traditional safety audits require at least two people for each audit, but often audit teams include more. Since requirements differ from jurisdiction to jurisdiction, the team can either be subcontracted by the project group from another consulting company, or be composed of jurisdiction (city or state) officials. Either way, securing their skills and time requires additional project funding.

The question then becomes, where is the additional funding going to come from, and which projects should be required to perform traditional safety audits. For state funded projects, most likely the state itself would provide the additional funding. Either the state provides the audit team (and therefore must pay them), or the consultants will need to charge the states more money to hire an audit team. However, additional funding is hard to come by when states have such tight budgets. In order to increase funding for individual projects, the states would either have to limit the number of projects they can afford to complete, or find some way to increase their income (most likely through taxes or service fees). On the private side, it will be the developers who pay more money so the consultants can either pay jurisdictional employees' time or hire another audit team. Since the need to perform the traditional safety audit will require additional money, it is reasonable to expect that a sensitive issue will be which projects should be required to perform safety audits and at what stage(s) should they be audited. To answer these

questions, jurisdictions will need to come up with a specific criteria and policy. However, what will be the means for enforcing compliance of the criteria and policy?

If jurisdictions derive criteria and policy for project auditing, groups will need incentive to follow these regulations. One option would be to withhold permission to allow projects not meeting the criteria (i.e. having an audit performed and then conforming the design to that audit) to be constructed within their jurisdiction. However, this would require additional manpower to enforce, which in turn requires additional funding.

Chapter 7: Safety Audit Software Packages

7.1: Background on IHSDM

In recent years, the Federal Highway Administration (FHWA) has been developing software packages that can be used to perform safety audits instead of contracting the use of an audit team. One such software is the Interactive Highway Safety Design Model (IHSDM). The official FHWA (2007) description of the IHSDM is, "...a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions..." (FHWA, 2007). The software pack is divided into six modules, each performing a different analysis function for the overall safety analysis of the design.

A technical guide for use on the IHSDM has been prepared by the FHWA contractor, Barone Shultz Friesen, which provides step by step instructions for operating the program. According to Barone Shultz Friesen (2005), the information is added to the IHSDM software using software commands and/or uploads from GEOPAK, MicroStation, ASCII Text, and Excel Spreadsheets files.

Currently, the IHSDM software is only available for two-lane rural highways. Future versions are under development to expand the technology for use on four-lane rural highways and urban/suburban arterials. The following sections address the current release of the two-lane rural highways.

7.2: Crash Prediction Module

The first module included in the IHSDM software package is the crash prediction module. According to FHWA (2007), the crash prediction module is designed to estimate crash frequency based on geometric and traffic characteristics. The following table summarizes the different elements that the IHSDM considers during crash analyses (FHWA, 2007):

Table 3: Crash Analysis Elements Used in Analysis by IHSDM

Roadway Aspects	Intersection Aspects
<ul style="list-style-type: none"> • Lane width • Shoulder width/type • Horizontal curve length and radius • Spiral transitions • Superelevation • Gradation (Running Slope) • Driveway density • Passing lanes • Two-way left turn lanes • Roadside hazard rating 	<ul style="list-style-type: none"> • Intersection skew angle • Traffic control • Left turn lanes • Right turn lanes • Sight distance

The module is currently designed to analyze three main types of intersections (FHWA, 2007). The first type is a three-legged intersection that provides stop control at the minor street approach. The second is a four-legged intersection layout with stop control at the

two minor street approaches. Finally, the third intersection layout is a four-legged intersection controlled by signals.

Crash analysis is performed using roadway and intersection base models, which FHWA (2007) says were derived using crash data from four different States. The base models are calibrated for the specific sites using accident modification factors provided by FHWA (2007). According to FHWA (2007), these modification factors account for geometric and traffic control design elements. The module also allows for an Empirical Bayes analysis that relates the module's crash estimates with site specific crash history (FHWA, 2007). For more information on the Empirical Bayes method, please see the Chapter 8 of the Appendix.

7.3: Design Consistency Module

The second module provided in the IHSDM software package is the design consistency module. The design consistency module was created to address safety issues on horizontal curves because statistical analysis has shown an over-representation of crashes on rural two-lane highways at horizontal curve locations (FHWA, 2007). The design consistency module evaluates a speed-profile model, free-flow speeds, and passenger vehicle speeds. The speed-profile is designed to analyze the 85th percentile speeds on horizontal, vertical, and horizontal/vertical curve combinations; tangent speeds; acceleration/deceleration rates at curve entry and exit points; and speeds on vertical grades (FHWA, 2007). According to FHWA (2007), the module has been calibrated using data collected from six States and identifies two common consistency issues, which

are speed differences between the design and estimated 85th percentile speeds, and changes that occur in the 85th percentile speed during the transition from the horizontal curves to or from its tangents.

7.4: Driver and Vehicle Module

According to FHWA (2007), the driver and vehicle module evaluates the operation of a vehicle on the roadway design and whether or not it could result in loss of control. To perform this analysis, the module is composed of both a Performance Model and a Vehicle Dynamics Model. The Performance Model evaluates driver components by estimating the potential driver speed and path along the roadway that occur when no other vehicles are present (FHWA, 2007). The Vehicle Dynamics Model estimates lateral acceleration, friction demand, and rolling movement of the vehicle based on the Performance Model assessment of the driver (FHWA, 2007).

The driver and vehicle module is not currently being released with IHSDM software package. FHWA (2007) says they have completed an alpha version of this module, which is currently undergoing testing. It is planned for release in future versions of the IHSDM.

7.5: Intersection Review Module

The intersection review module is designed to evaluate intersection elements. Based on information from FHWA (2007), the module can be broken into four different categories, which are intersection configuration, horizontal alignment, vertical alignment, and

intersection sight distance. This module is designed to evaluate multiple intersection configurations, including multileg intersections, skewed intersections, T-intersections, and intersections with multiple minor road access points on one side of a major road. The horizontal alignment analysis looks at how horizontal curve placement in the proximity of the intersection can influence safety, whether the curve is at the intersection itself or near an intersection approach (FHWA, 2007). The vertical alignment section addresses the safety of crest curves at the intersection, crest or sag curves at intersection approaches, steep grades through the intersection, and the minor-road profile as it passes through the intersection (FHWA, 2007). According to FHWA (2007), future editions of the intersection review module will also include the ability to assess design compliance. This would include the ability to verify adequate corner radius, turning lane designs, intersection angles, and sight distance triangles (FHWA, 2007).

7.6: Policy Review Module

The policy review module evaluates the roadway design for compliance with design standards (FHWA, 2007). The module already contains design standards for the 1990, 1994, 2001, and 2004 editions of the AASHTO book, *A Policy on Geometric Design of Highway and Streets*, but also allows the user to input jurisdictional standards applicable to each project (FHWA, 2007). According to FHWA (2007), the module checks for standard compliance for roadway cross sections, horizontal alignments, vertical alignments, and sight distance. The following table outlines the checks performed in each of the categories as identified by FHWA (2007):

Table 4: Policy Review Elements Used in Analysis by IHSDM

Cross Section	Horizontal Alignment	Vertical Alignment	Sight Distance
<ul style="list-style-type: none"> • Travel way width • Auxiliary lane width • Shoulder width • Roadway cross slopes • Rollover cross slope on curves • Bridge width 	<ul style="list-style-type: none"> • Radius of curvature • Superelevation • Curve length • Compound curve ratio 	<ul style="list-style-type: none"> • Tangent grade • Curve length 	<ul style="list-style-type: none"> • Stopping • Passing • Decision

According to FHWA (2007), future editions of the software package will also include clear zone, roadside slope, normal ditch design, and superelevation transition checks.

7.7: Traffic Analysis Module

The traffic analysis module uses TWOPAS traffic simulation software to predict traffic conditions for current or future traffic volumes at roadway projects (FHWA, 2007). The TWOPAS software runs off of geometric data provided by the other IHSDM modules and performs analysis based on the *Highway Capacity Manual* procedures (FHWA, 2007). According to FHWA (2007), the software can determine average speed and percent time spent following values for the roadway design and can simulate grades,

curves, sight distance restrictions, no passing zones, passing lanes, and climbing lanes in its analysis.

Chapter 8: Limitations of Safety Audit Software

While the Interactive Highway Safety Design Model (IHSDM) provides some advantages, there are a few potential limitations to its use. The first of these limitations is the small number of roadway facilities the software is currently able to evaluate. As of now, the IHSDM software is only applicable for two-way rural highways (with short four-lane sections). This means that other facilities, for example freeways, downtown corridors, suburban arterials, etc., cannot be analyzed using the program, which makes its applicability to projects fairly limited. Alternate versions of the IHSDM are currently under design for future release, which would allow for the analysis of four-lane rural highways and urban/suburban arterials. These facilities were the next considered for development because they typically experience the highest crash rates. While these future editions will increase the number of roadways the IHSDM is able to evaluate, it will still not enable the product to fully serve all roadway types.

Another potential problem of using the IHSDM software for safety analysis is that it could create a tendency for users to rely too heavily on the program outputs. When using the program, roadway characteristics are entered into the file and then safety results are displayed to the user. The idea of the program is for it to alert the user of any areas prone to safety deficiencies. The user should then investigate into these areas more thoroughly. Although investigating the safety deficient areas on their own will inherently take care of spot checking these outputs, other outputs should still be checked as well. Spot checking the outputs will ensure that all the information was entered correctly and that the results being received are reasonable. When users rely too heavily on design aid programs, such

as the IHSDM, discrepancies can sometimes go unnoticed and then the design outputs are no longer reliable. In order to facilitate the verifying of outputs, IHSDM users should also have general training in safety so that they understand how to correctly interpret the information the program is providing.

Another area for discussion is whether the program provides nominal safety analysis or substantive safety analysis. Nominal and substantive safety are two terms created by Ezra Hauer (1999) to describe the difference between describing something as safe because it meets certain standards (nominal safety) and safe because it has been individually evaluated to determine what other safety measures, beyond just those that meet standards, should be provided (substantive safety). Substantive safety is achieved by evaluating future crash numbers and severity associated with a location and then designing to reduce these values. Ezra Hauer (1999) makes the point that something that meets safety standards is not necessarily safe. The IHSDM program checks roadway designs and traffic engineering features to certain standards and/or guidelines, and, based on the description of the crash prediction module provided by FHWA (2007), the software also appears to provide for substantive safety. The crash prediction module identifies areas that may result in a high crash frequency. Although the module does not currently estimate the severity of crashes, it has been suggested that future editions may incorporate this analysis method. This would be done using some form of statistical modeling similar to that used for crash frequency. Once the crash frequency and severity have been identified, the problems identified by the software and crash information can

be used by the engineer to determine what features to add or remove to achieve substantive safety.

Chapter 9: Conclusions

At the beginning of this thesis, several benefits of safety audits were identified. As a means of comparing performance ability of traditional safety audits with new software capabilities, the two options will be evaluated on their ability to provide these benefits.

The first of these benefits is the ability to provide a greater prominence of transportation safety during the stages of the design process. Traditional safety audits are usually performed at one or two phases of the design process. When using this method of auditing, the prominence of safety would result from the attention to safety required by transportation professionals knowing their designs will soon be checked for safety characteristics. In comparison, the IHSDM software is designed in such a way that it can provide constant feedback on the design elements throughout the entire process. Since the IHSDM software provides constant feedback, it would most likely create a greater prominence of transportation safety during the design process than traditional safety audits.

Another benefit of safety audits is they create an opportunity for professionals knowledgeable in safety practices to provide feedback to designing engineers on their current practices. Traditional safety audit procedures allow the safety professionals and transportation engineers to meet and discuss the current design and its safety elements. This provides an open forum environment where the designers can ask questions related to their current project or design in general and gain feedback from individuals whose professional life is immersed in these topics. When the IHSDM software is used in place

of a traditional safety audit, it will still provide feedback on the design to the engineer (by flagging potential design issues) and provide qualitative findings on different design alternatives (which is more safe than the other). However, the software cannot provide the same type of open forum and learning environment that a traditional safety audit can, which means that traditional safety audits provide more directly educational feedback to the design engineers on their practices.

Safety audits have the potential ability to reduce the number/severity of crashes experienced at locations. Both traditional safety audits and IHSDM software audits alert designers of safety concerns, so they can be mitigated before implementations, which means that both can reduce the number/severity of crashes at locations. However, more research would need to be conducted to determine whether one method provides greater reduction than the other.

Safety audits have also shown the ability to reduce the need of future remedial work to designs, which can be very costly depending on the level of remedial work needed. By locating unsafe conditions before project completion, the project team can save both lives and costs. Since both the traditional safety audits and IHSDM audits provide feedback to designers on safety problems during the design process, they both have the ability to identify safety problems preconstruction and thus reduce remedial work. However, the IHSDM software may have one advantage in this area over the traditional audit methods. The IHSDM software can be run by an individual engineer and used to check the design process intermittently throughout the entire project schedule. Traditional safety audits are

usually preformed at only one or two stages in the design process. Since the IHSDM software can provide feedback at all stages (for limited cost), design deficiencies can be identified earlier on (i.e. when they first occur) than if the design were checked later on in the process by the audit team, for example at the final design stage. This eliminates the need for costly design revisions later in the process, when more aspects are involved, because they can be revised immediately on a much smaller scale.

Another benefit of safety audits is that they provide large crash reduction savings while typically using less than 0.5 percent of the total project cost. This benefit statistic was developed referring to traditional safety audit methods. However, use of the IHSDM should required less funding than performance of a traditional safety audit. The software can be operated by an individual engineer and bases a lot of it's evaluation on input from other design tools commonly used during the design process. This means that the software requires less manpower to operate than an entire audit team, and therefore less funding. As a result, more projects can afford to be audited using the IHSDM software than those using traditional safety audits, which makes the IHSDM software more advantageous.

Safety audits also have the ability to progress roadway design from nominal safety to substantive safety. Nominal and substantive safeties are differentiated by the fact that substantive safety provides safety measures beyond compliance with design standards. Substantive safety is achieved by using crash frequency and severity predictions to dictate additional safety features or redesign elements that should be made to provide

additional safety. Traditional safety audits are able to identify features needed to progress projects to substantive safety using subjective expert opinions of the designs. However, in order to achieve true substantive safety, traditional safety audits would need to use a form of modeling to predict crash numbers and severity. IHSDM software is able to provide partial substantive safety using its crash prediction module, which predicts crash frequency for the design. Since substantive safety also requires the use of predicted crash severity, it has been suggested that future editions of the IHSDM also include severity prediction capabilities. With crash and severity predictions from future IHSDM editions, engineers can then utilize this information to determine what project elements need to be added or removed to achieve substantive safety levels for their projects. In this case, both traditional safety audits and IHSDM software based audits will be able to provide substantive safety to projects.

The last benefit identified earlier is that safety audits allow for input from interdisciplinary agencies that would otherwise be unlikely to have a say in the design process. Traditional safety audits allow for this by placing representatives of these groups on their audit teams. Examples of these representatives include multimodal advocates, emergency service specialists, human factors specialists, etc. Based on the information available from the FHWA (2007), it appears that the IHSDM is not currently able to provide evaluations that advocate for the views of these representatives. The driver/vehicle module under development could be a good location to place elements of human factors for analysis, but the module descriptions available do not indicate if this is a plan. Other specialties, like emergency services and multimodal advocacy, would most

likely require the creation of individual modules. The United States requires that public hearings be held for all projects, which could be a good place for these advocates to voice their concerns if IHSDM software is used to replace the traditional road safety audit process. However, in this environment the advocates are treated more like members of the general public instead of key design contributors. With traditional safety audits the advocates are given the chance to be more involved throughout the design process. Based on this, it appears that the traditional safety audits have a better ability to provide this benefit.

The evaluation of these benefits can be seen summarized in the following table.

Table 5: Evaluation of Previously Discussed Benefits

Benefit	Traditional Safety Audits	IHSDM	Comments
Greater prominence of safety during design	Good	Better	If used throughout the entire project, the IHSDM can provide constant feedback. Traditional Safety Audits only provide feedback at the exact time of the audit.
Provides feedback to professionals on their designs	Better	Good	Traditional Safety Audits provide an open forum and learning environment during the audit process that cannot be replicated by the software.
Ability to reduce future number/severity of crashes	Good	Good	Both options are capable of this. More research is needed to determine if statistically one method is better than the other.
Progression towards substantive safety	Possible	Possible	Traditional Safety Audits are able to progress towards substantive safety based on expert opinions, and can achieve true substantive safety when using crash number and severity prediction modeling. If the IHSDM adds a severity prediction model, then it will be able to provide substantive safety in the future.
Input from interdisciplinary agencies	Better	Possible	Traditional Safety Audits allow for interdisciplinary input by including representatives on their audit teams. For projects using IHSDM, interdisciplinary agencies can only provide input during public hearings.

While evaluating the two options based on the originally identified benefits of safety audits have provided good discussion over which option is more advantageous, there are other areas to be considered as well. A benefit of the IHSDM software is that it has the ability to provide consistent results everywhere. This, however, is contingent on the fact that the users are competent and well trained in its operations. With traditional safety audits, the results of the audits are dependent of the members of the audit team. The same project could be audited by two separate audit teams and could result in two separate lists of recommendations. The IHSDM software, however, should always provide the same recommendations on the same project. Consistency in design is beneficial in that it provides a good basis for driver expectancy and also demonstrates the same set of principles repeatedly to designers.

Another benefit of the IHSDM software audit is that it protects the design process of the project team's company. Traditional audit teams are composed of competing consulting firm groups or jurisdiction employees (which may someday become competing consultants). Many design companies prefer to safe guard their design strategies from competing organizations in order to preserve the competitive edge. If they are forced to allow competing, or possible competing, groups to view the intimate details of their design formation, it could jeopardize the preservation of their competitive edge. This could cause firms to feel uneasy about allowing the audit to take place. Using IHSDM software allows the audit to be completed by their own personnel, which protects their design strategies.

Based on the previous discussion, the final recommendation of this thesis is that IHSDM software is most appropriate for use in the United States. The software's previously discussed advantages and significantly lower manpower and funding requirements make it a more desirable option for the United States. However, in order to increase its effectiveness, severity prediction modeling should be added to the program. Also, as discussed earlier, engineers knowledgeable in safety should spot check outputs from the IHSDM to ensure reasonable outputs are received. This will prevent users from over relying on the software. It should also be noted that the IHSDM is not intended to be a stand alone product. The goal of the IHSDM is highlight safety deficiencies with the expectation that engineers will later perform their own analyses to confirm the findings and develop solutions. This will also discourage any assumptions that because the program does not identify safety deficiencies it must be safe. The IHSDM software is designed in a way that makes it easily applied to the majority of engineering projects, meaning that a larger number of designs can be exposed to safety evaluations than those that would be from traditional safety audits. Its widespread accessibility far outweighs any limitations of its use not mitigated by the provision of follow-up engineering suggested by this thesis. Its accessibility will be further expanded as more versions of the IHSDM become available (i.e. for different roadway facilities), which is sure to follow its acceptance as use as a new design standard in the United States.

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Appendix A

University Honors College Thesis
Literature Review Section
Prepared for: University Honors College
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Appendix Table of Contents

Chapter 1: Introduction	43
Chapter 2: Data Providers	44
2.1: Police	44
2.2: Self Reporting	45
2.3: Databases	47
Chapter 3: Ways to Collect Data	48
3.1: Forms	48
3.2: Computers	48
3.3: Crash Scene Investigation	50
3.4: Data Collection	50
Chapter 4: Resolving Data	52
4.1: Consistency	52
4.2: Reporting Thresholds	54
4.3: Computerized Database	55
4.4: Underreporting	56
Chapter 5: Crash Investigation (Site Visit)	59
5.1: General	59
5.2: Physical Characteristics	60
5.3: Operational Characteristics	61
5.4: Dynamic Approach	62
6.1: Link Node/Nodal	63
6.2: Route-km/Milepost	65
6.3: Reference Point	66
6.4: Coordinate/Global Positioning System Based	67
6.5: Loran C-Base	69
Chapter 7: Safety Audits	70
7.1: Introduction	70
7.2: Stages/Types	70
7.3: Details	71
7.4: International	72
7.5: Benefits	73
Chapter 8: Methods for Identifying High Risk Locations	74
8.1: Blackspots	74
8.2: Severity	74
8.3: Rates	75
8.4: Crash Frequency	78
8.5: Combination Methods	79
8.6: Typology	80
8.7: Index	81
8.8: Prediction Models	83
8.9: Empirical Bayesian	84
8.10: Accident Patterns	84
8.11: Hazardous Roadway Features Inventory	85
8.12: Cost	85

8.13: Other	85
9.1: Statistical.....	87
9.2: International.....	87
9.3: Treatment Strategies	89
9.4: Analysis Period.....	90
Chapter 10: Problem Diagnosis at Hazardous Locations	93
10.1: Site History	93
10.2: Site Observation.....	94
10.3: Site and Road Categorization	97
10.4: Collision Diagram.....	98
10.5: Spot Maps	98
10.6: Tables.....	99
10.7: Traffic Data.....	99
10.8: Environmental Studies.....	103
10.9: Additional Techniques.....	104
Chapter 11: Countermeasure Selection.....	105
11.1: Estimating Benefits and Costs	105
11.2: First Year Rate of Return.....	105
11.3: Net Present Value	106
11.4: Net Present Value/ Present Value of Cost Ratio.....	107
11.5: Benefit-to-cost (B/C) Ratio.....	107
11.6: Benefit-to-Cost Ratio/Incremental Benefit-to-Cost Ratio	108
11.7: Internal Rate of Return	109
11.8: Cost-Effectiveness Method.....	109
11.9: Rate-of-Return Method.....	110
11.10: Time-of-Return Method.....	111
11.11: Net Benefit Method	112
Chapter 12: Countermeasure Evaluation	113
12.1: Monitoring Improvements	113
12.3: Accident-Based Evaluation.....	115
12.4: Non-Accident-Based Evaluation	119
12.5: Program Evaluations.....	120
Chapter 13: Conclusion.....	123

Chapter 1: Introduction

The following is a summary of information gathered from several safety analysis sources.

The research was initially conducted as part of a contract with ODOT to look into current practices and trends, both nationally and internationally, of safety investigations. This literature review contains information collected as a part of that contract, but that has now been reorganized and expanded to aid in the progression of the Honors College Thesis requirements.

Chapter 2: Data Providers

2.1: Police

When a crash occurs, police officers are the first party to the scene in charge of interpreting what has happened. They are usually charged with recording the location of the crash, assessing the severity, and interpreting its cause (e.g. lane change or running a red light). These documents, or crash records, are later used by crash investigators to assess the environmental contribution to the crash.

Increased cooperation between police officers and crash investigators can yield large benefits towards data collection. It can improve the accuracy of the data received, which can therefore improve the accuracy of the diagnosis (PIARC, 2003). Something else to recognize is the difficulty the untrained eye has in knowing what information is crucial. As Retting (2001) points out, police officers are may not be able to attribute the crash to the important environmental factors because they lack the training to identify these deficiencies. Retting (2001) also points out police officers can miss these factors because they are busy with clearing the crash scene and tending to legal considerations.

Confusion can also occur over the importance of the crash records. Police officers often assume the paperwork is strictly for insurance reasons and can fail to see its potential for crash prevention (PIARC, 2003). PIARC (2003) suggests providing training sessions where safety representatives can demonstrate the importance of each piece of information. They (PIARC, 2003) point out that consistent training of police officers will

create consistent data. Creating a vested interest in where the data is used can lead to increased quality of information. Ogden (1996) has also pointed out that involving police officers in the use of their data collection can increase accuracy because it creates a sense of value in their work.

An area in need of strengthening is the way police officers locate the crash. Police officers who are not familiar with the area the crash occurs in can record its location incorrectly (Ogden, 1996). Other potential sources of error involve crash diagrams, crash descriptions, or improper location identification (Graham et. al., 1975).

2.2: Self Reporting

Self reporting of crashes within the state of Oregon is supervised by the Oregon Department of Motor Vehicles (DMV). All information for the self reporting section of this literature review was gathered from the Oregon DMV website. As of January 1, 2003, self reporting is required for crashes involving: Damage to a vehicle involved in the wreck of over 1500 dollars, damage to any property resulting from the wreck over 1500 dollars, any injury, and death. Prior to January 1, 2003, reporting was required for wrecks involving: Damage to any property exceeded 1000 dollars, any injury, or death. Also, any reportable crash must have occurred on public facilities. The self reporting form must be filed within 72 hours of the wreck. Failing to submit a form is punishable by revocation of driving privileges. Also, even if an officer at the scene of the wreck files a crash report, the parties involved are still required to submit these forms to DMV. If a wreck qualifies for self reporting, even if the participants are not Oregon residents they

must still submit. The DMV states it does not determine fault for the wreck, but does place the incident on the driving records of all those involved. The Oregon Traffic Accident and Insurance Report forms have been attached (both periods).

The self reporting form in use after January 1, 2003, can be obtained at either the DMV or online at their website. This form collects information on:

- Time of crash: Day of week, hour
- Location of crash: County, road, distance from nearest intersection or city
- Number and type of vehicles involved
- Insurance information of drivers
- Qualifier: e.g. exceeded 1500 dollars in damages
- Statement of what happened
- Intended movement path
- Weather, light, and roadway conditions
- Direction of travel of both vehicles (N, S, E, W)
- Safety equipment employed: Seat belts, air bags, car seats, etc
- Schematic of damage to vehicle and travel path
- Damage amount to vehicle (dollar amount)

A supplemental form is required if the crash involved more than two vehicles. It is intended to be attached to the Oregon Traffic Accident and Insurance Report form. This form collects the insurance information of all drivers involved. It also collects

information on injury, vehicle type, intended movement, weather, road surface, and lighting conditions at the wreck.

2.3: Databases

Many authors have discussed the idea of creating a database of crash information for jurisdictions. According to PIARC (2003), crash data has a tendency to be underutilized and creating a database with query options would allow safety analysts to research and analyze crash data. According to PIARC (2003), the database should include the ‘who, what, when, where, and why’ of each crash, and should have linking capabilities to roadway and traffic characteristics.

Once a database has been established, there are details that need to be attended to. According to PIARC (2003), it is essential that the database have consistent terminology. For example, a ‘minor injury’ severity should be defined the same everywhere that data is collected for use in the database. PIARC (2003) also brings up the need for universal reporting thresholds, meaning the same type of crashes should be required for reporting and inclusion in the database at all the locations. Ogden (1996) points out a need for concern over the source of data used in the database. When it comes to the self reporting of crashes, Ogden (1996) questions the reliability of the data and how it should be controlled.

Chapter 3: Ways to Collect Data

3.1: Forms

Forms completed by police officers at crash scenes are a main source of data for crash investigators. Forms can be designed for narrative responses or checklists. Eyewitness statements, photographs, and diagrams of the scene can also be very helpful when provided. In designing forms, it is crucial that they are easy to use. According to PIARC (2003), easy-to-use forms are a pre-requisite to consistent data collection.

The use of forms also presents a downside. As Ogden (1996) points out, forms cannot always effectively convey necessary information; crashes will occur that do not fit within the form format. While standardizing data collection with forms can help with consistency, they cannot provide as much information as a well written police report. Written police reports provide the most complete documentation of crash scenarios (Retting, 2001). This is because of their descriptive narratives and diagrams, which can shed light on pre-crash events and vehicle movements (Retting, 2001).

3.2: Computers

The use of computers at crash scenes can provide numerous advantages towards data collection, as pointed out by PIARC (2003). The first of these advantages is the elimination of errors that occur from sloppy handwriting. When writing is difficult to interpret, valuable data and meaning can be lost. Another advantage is the ability of computer software to perform logic checks. This can prevent errors from occurring

almost immediately. An example of a logic check would be to check that a crash classified as a rear-end was reported involving two cars. Computer usage can also speed the process of data collection when the appropriate interface capabilities are utilized. Portable computers can be used to receive information from barcode scanners, GPS receivers, and digital cameras. This ability is significantly advantageous when multi-vehicle crashes are present. Computers are also helpful to police officers because they can be used for other non-crash related tasks. Portable computers can also be found in pen-based form. These are helpful because crash diagrams can be sketched directly into the computer file. Pen-based computers also require less training prior to use because recording information in them is similar to recording it on a paper form.

PIARC (2003) has also identified disadvantages that occur with using portable computers. Computers and computer programs can be intimidating to use for people who lack computer experience. They can also increase the time required for completing reports when used by people who are not efficient at typing. Portable computers can also be difficult to handle and/or heavy when used outside of the police vehicle. They are also fragile and prone to damage. Something else to consider is that prosecutor will not always accept electronically based crash summaries. They often required hand written and signed versions.

Onsite data collectors can also be used in pairing with computers. PIARC (2003) suggests that barcodes on cars and licenses can be used to quickly transfer relative information. When used with computers, they will allow driver history and vehicle information to be

added to crash reports. Barcodes also eliminate chance of error. Expert Systems can also limit the work required by police officers by collecting information for them. In addition, they add consistency to subjective areas, such as crash severity, and increase the accuracy of data collection.

3.3: Crash Scene Investigation

Immediately following a crash, several items of information need to be document.

PIARC (2003) points out that a unique location needs to be given to the crash so that it can be tracked for future studies. PIARC (2003) points out that the time of the crash is also important and should be expressed in terms of the date (day, month, year) and time of day. PIARC (2003) suggest that all people or items involved be recorded, such as persons and/or animals injured, objects hit, etc. PIARC (2003) also suggests recording the results of the crash in terms of persons involved and corresponding severity classifications. PIARC (2003) states that environmental factors should also be noted, including weather, lighting, and pavement conditions, etc. And finally, PIARC (2003) recommends attempting to identify the cause of the crash, vehicle maneuvers/collision type, original directions of travel, etc.

3.4: Data Collection

Safety studies require several forms of data, the first of which is crash data. Crash data should include location of the crash, what it was caused by, time of day, who was involved, the result of the crash, and environmental circumstances that may have

contributed to events. Once this information is collected it is generally encoded into a crash database. One of the most difficult attributes to encode is why the crash occurred. As Ogden (1996) points out, many times researchers need to retrieve the original crash report to investigate the cause of a crash.

Aside from crash data, Ogden (1996) has identified road and traffic data as valuable information to have available when classifying hazardous road locations. Adding to this list, PIARC (2003) has identified a need for information on the people and vehicles involved in the crash, the result of any hospital treatments (for severity classification), and information on any other contributing factors.

Numerous sources are available for data collection, several of which have been identified by PIARC (2003). Crash data can be found in the crash data files created after each crash. Roadway data files usually exist, which contain site information for the crash location. Traffic data files will contain traffic volume and other operational characteristics. Hospital files are a good source for information needed for severity classification, such as extent of injuries and outcome of stays. PIARC (2003) points out that hospital files provide more reliable summaries than police statements. Vehicle registration and driver files can also provide helpful information.

Chapter 4: Resolving Data

4.1: Consistency

It is important to perform consistency checks within the database. Consistency errors can result from mistakes during the crash report, definitions, road names, and thresholds.

As PIARC (2003) has pointed out, it is always important to check crash reports for consistency after their completion. Specifically, location, time, number of vehicles, crash type, casualty numbers, and severity classification should be reviewed for errors. Errors can arise from simple human error or misinterpreting definitions of data items. An example of an inconsistency caused by human error would be if an accident is recorded as a rear-end collision, but only one car is involved. Consistency throughout the report can be checked manually or with algorithms if computers are used on the scene. It is best for errors to be detected early so the responsible police officer has the opportunity to correct them before information is lost. Along with misunderstanding definitions of data items, which PIARC (2003) attributes the majority of data errors to, is the idea of inconsistencies created by *changes* in definitions. In his book, Ogden (1996) brings up the idea that once the definition of a data item is changed, comparisons are no longer valid. Crash reports created prior to the change will be based on a different definition than ones created after, which makes them incomparable. Furthermore, keeping with PIARC (2003)'s point, if all police officers do not understand this change, information will be recorded incorrectly.

Inconsistencies can also exist in reporting crash locations based on roadway names. Graham et. al. (1975) has highlighted this issue by describing how roadway name changes, dual naming, or repeated intersecting can create confusion with crash records. When roadway names are changed throughout the development of a city, it is important to associate all previous crash records (for the original name) with the newer crash records (associated with its new name). If links are not created within the database, a multitude of problems can arise. Another source of error exists when roadways have multiple names. This is common with highways, which can have route designation numbers as well as street names. Graham et. al. (1975) recommends using the route number as the roadway's primary index and the street name as its secondary index. Another source of error, that can easily go unnoticed, occurs when two roadways intersect more than once. If the two intersections are not coded differently into the database, their crash records will be grouped together incorrectly. Furthermore, if identified too late, this mix-up can be difficult to reverse. To solve this problem, Graham et. al. (1975) recommends using further information to designate which intersection is under consideration. One way to do this would be to denote the two intersections as either north and south or east and west. This same problem can also exist when two roadways merge and then re-separate. These mergers should also be identified as either north and south or east and west.

One of the benefits of cataloging crash reports is they allow for comparisons of information. Problems can arise, however, when crashes are compared from different jurisdictions. Ogden (1996) has pointed out variations exist between jurisdictions

regarding definitions and reporting thresholds. These variations make it unreasonable to compare their crash statistics. For example, property damage only crashes may only require reporting for a certain jurisdiction when the damage exceeds a value of five hundred dollars. Another jurisdiction may require reporting of anything exceeding three hundred dollars. These different reporting requirements make it impossible to obtain an unbiased comparison between the two because the second jurisdiction is more inclusive in its crash reporting. Jurisdictions may also vary in their severity classification. This can occur in the number of severity levels accounted for and the definitions of each level. This results in the inability to compare crash statistics dealing with severity.

4.2: Reporting Thresholds

In order to maintain valid comparisons, it is important that reporting threshold be consistent throughout the state. If thresholds are not consistent, it makes it impossible to accurately compare the crash statistics between jurisdictions. When jurisdictions have different requirements, the crash statistics of some are more inclusive than others. PIARC (2003) has identified some typical guidelines used for reporting thresholds. According to PIARC (2003), crashes should be reported if: personal injury is involved, a vehicle is in need of towing, injury is caused to a person other than the driver, or the crash occurred on a highway.

PIARC (2003) points out that most property damage only crash thresholds are based on exceeding a monetary value. These values should be adjusted as appropriate to correspond with the inflation of repair costs. These adjustments, however, can create a

new source or problems. When not monitored closely, changes in repair costs can occur without changes in thresholds. If, for example, the cost of repair increases without adjustment of the threshold, crashes will qualify for reporting that should not. This can threaten statistical integrity.

4.3: Computerized Database

Computerized crash databases provide quick and easy access to lots of information. They are particularly essential for areas that have large amounts of data. Databases offer several functions that can make crash analyses more convenient. When programmed correctly, they can perform statistical analyses such as computation of rates and severity indices. They are also capable of cross-tabulations, graph generation, and can be set up to automatically flag locations that exceed preset thresholds. Thresholds can be set for different types crashes, severity, etc.

There are several things that are helpful to include in crash databases. According to PIARC (2003), databases should include crash data, roadway inventory files, and traffic data. Other good items to include are motor vehicle files, driver files, hospital files, etc. Including all this information, however, can take up a lot of room. One way to minimize space requirements on computers is to code the data. There are programs available which can perform this function while still displaying the original input for users. Having access to the un-coded form is helpful because it aids in understanding.

Although databases can be helpful for maintain crash statistics, there are also inherent problems. Ogden (1996) sites that around 5% of crash files containing coding errors. These errors occur either during original creation of the original report or entering into the database. It is also important to keep the database updated. When crash records are abundant and an agency is unable to enter them fast enough, the database is no longer current. This becomes a problem when it is used to analyze crash trends because it is no longer based on current information (Ogden, 1996). Furthermore, databases may not always be able to give a clear picture of what is going on. As Ogden (1996) points out, databases only provide information on crashes that are occurring, not ones that are deliberately avoided because of assumed risk (i.e. by not using the location).

4.4: Underreporting

Underreporting is an issue for crash analysts because it can mean crash statistics do not represent the reality of the situation. Underreporting of specific types of crashes is the most common form seen. As Ogden (1996) writes, “In a comprehensive international review, James (1991) found that accidents involving children, pedal cyclists, pedestrians, and minor injury were all substantially under-reported” (Ogden, 1996, pg 93). According to Ogden (1996), underreporting can also lead to random bias. There are several contributing factors to underreporting. The rest of this section discusses reasoning related to this.

There are several reasons why crashes experience underreporting that have been summarize by PIARC (2003). The first of these reasons are based on driver choices.

Drivers may choose to avoid reporting their crashes because they do not understand their legal obligation, want to avoid bureaucracy, are unaware of resulting injuries, or want to avoid corresponding insurance penalties. The second reason has to do with the reporting party. When police officers are experiencing a large workload, there may not be enough time available to them for reporting all crashes. This is evident in the fact that when bad weather occurs, underreporting tends to increase. Underreporting is common for bad weather crashes because there are not enough police officers to attend all the crashes in time. Also, the commitment of police officers to make time available to fill out the required paperwork can vary between stations. This is particularly an issue when the report forms are long. According to PIARC (2003), there is a 'golden mean' related to report length and reporting success. The 'golden mean' represents the correlation between the number of questions on report forms (i.e. length) and the likelihood they will be completed. The longer the report form, the more likely underreporting will occur; the shorter the report form, the more likely it is that crashes will be reported. However, shorter forms mean less data is available.

PIARC (2003) also points out that underreporting can vary by groups and type.

According to them, bicycle and pedestrian crashes are more likely to be underreported than motor vehicles. Also, single vehicle crashes are more at risk for underreporting than ones involving multiple vehicles. Crash severity also plays a role. Fatal crashes are the most likely to be reported and thus have the most reliable data, whereas property damage only are the least likely and therefore have less reliable data. PIARC (2003) also points

out that the chance of reporting is related to the age of the injured person. The older they person is, the more likely they are to report the crash.

Chapter 5: Crash Investigation (Site Visit)

5.1: General

Site visits are important in creating an understanding of contributing factors to crashes. It is often helpful to schedule the site visit during conditions similar to when the crash occurred (Graham et. al., 1975). For example, if the crash involved wet pavement, it would be good to visit the site during rain. This aid is better understanding how the environment and driver's reactions to it may have contributed to the collision.

There are several general things that should be done during a site visit. The first of these is to drive through the site. At an intersection, for example, it would be a good idea to drive through from all different approaches. It is important to understand how drivers view and react to the environment (Graham et. al., 1975). Ogden (1996) goes as far as to say that drivers should actually execute the maneuvers that have been identified as problematic during their drive through to see if any new insight can be gained as to why they are a problem. Things to note would be whether aspects of the environment, such as lighting, vegetation, road alignment, etc, are combining to create confusion for drivers.

After driving through the site, investigators should stand by and watch driver behavior as well. It is important to identify any forms of unusual behavior and their cause. Examples of driver behavior to monitor would be late braking when entering sharp curves, evasive actions at intersections, etc (Ogden, 1996). These types of behaviors are important because they contribute to crashes. Other helpful measures include speaking with people

who work or live in the area and taking pictures (Graham et. al., 1975). Ogden (1996) suggests taking pictures of the approaches.

5.2: Physical Characteristics

The physical characteristics of the site should be evaluated during the site visit to determine whether they could have contributed to the crash. Graham et. al. (1975) has put together an extensive list of items to evaluate. The first item is sight distance. The site should be checked to see if adequate sight distance is provided and whether it is possible to remove or lessen any obstructions. Roadway alignment should be considered and roadway width should be checked to make sure enough room is provided for drivers. Curb radii should also be measured to see if they are too small. Pedestrian crosswalks should be evaluated for correct placement and to determine if maintenance, such as painting, is required. Any signs and signals at the site should be compared with MUTCD standards to see if requirements are met. Also, signs should be checked for clarity, size, placement, etc and signals should be checked for placement, signal head use, and timing. Pavement markings should also be checked for clarity and location. Channelization should be evaluated to see if it meets needs for reducing conflict areas, separating traffic flows, defining movement, etc. Any provided parking needs to be evaluated. Check to see whether it negatively affects sight distance, vehicle paths (through or turning), or traffic flow. Other items to check include speed limit appropriateness, number of lanes provided in comparison to traffic volume, street lighting, driveway placement, and pavement conditions.

5.3: Operational Characteristics

Operational characteristics are also an important aspect to check during site investigations. Similar to the list of physical characteristics provided, Graham et. al. (1975) has put together a group of operational characteristics that should be evaluated. The first of these is whether or not opposing traffic is adequately visible to drivers. This is something to note during a preliminary drive through. Roadway users should also be observed to see whether they respond correctly the traffic control devices within the area, including signals and signs, or have difficulty locating correct vehicle paths. Drivers should also be observed to see whether they appear to understand provided guidance information, such as street names. Vehicle speeds need to be monitored to determine if they are too high or low and vehicle delay should be checked for reducing potential. Traffic volumes should be compared to site characteristics to see if they are adequately matched. The site should be monitored for traffic flow deficiencies or conflict patterns, particularly associated with turning movements. Pedestrian movements should also be monitored to see if they contribute to conflicts, as well as parking. Parking maneuvers, in addition to all maneuvers at the site, should be checked for traffic violations. Sites should be evaluated for one-way operations as well to see if this would result in improvements.

In his book, Ogden (1996) has provided additional operational checks for site visits. First, Ogden (1996) suggests evaluating specific traffic movements to see whether prioritizing or prohibiting them would benefit the overall flow. Investigators should check whether alternate routes are available where portions of traffic could be redirected to reduce crashes. Selected alternate routes should have a lower crash potential than the site under

investigation. Environmental factors need to be assessed for operational problems. Ogden (1996) points out that if nighttime crashes are in significant excess of daytime, additional nighttime protection may be required.

5.4: Dynamic Approach

The dynamic multi-causal approach has been identified by PIARC (2003) as another form of crash scene investigation. This approach uses crash models and reconstruction to evaluate the sequencing of crash events. Tire markings, calculated deformations, etc are used to conduct dynamic reconstruction. This reconstruction, along with the fault-tree method, is then used to analyze potential crash sequencing.

Chapter 6: Methods for Locating Crashes

6.1: Link Node/Nodal

Several methods have been identified for recording the location of crashes. The first of these is the link node/nodal method. Nodes are numbered and placed at easily identifiable locations of roadway, and links are used to connect them. Most commonly, nodes are selected as intersections, but they can also be bridges, interchanges, roundabouts, city boundaries, etc. When crashes occur, their location is specified as some measured distance and direction from a node.

When nodes are created, boundaries must be taken into account. This deals specifically with how far from the intersection or landmark to extend the boundaries of the node before it becomes a link. PIARC (2003) has pointed out that it is important to make nodal boundaries large enough that crashes associated with that node are included. An example of this would be a crash at an intersection queue, which should be included as a crash within that node. However, the downfall is that if nodal boundaries are made too inclusive, crashes that are not related to node are included. This added area surrounding the intersection (or other node characteristic) and included within the nodal boundaries is known as the 'zone of influence'. PIARC (2003) suggests checking the relevance of the zone of influence during the following stages of analysis. To avoid statistical biases, use the same dimensions for the zone of influence of specific types of nodes for all similar roadways. During the diagnosis stage, crashes included in the zone of influence should be checked to make sure they were correctly characterized as node related.

In addition to nodal sizing, it is important to check link sizing. PIARC (2003) has suggested that the optimal sizing of links is between 500 and 1,000 meters in length. Since links can also be identified as hazardous locations, adequate sizing is important. One inherent problem with the link method, identified by PIARC (2003), is that it creates blind spots at the boundaries. This means that a high crash location may exist but it will go unnoticed since it is split between two link boundaries, neither of which independently would qualify as a hazardous location. To avoid this situation, PIARC (2003) has recommended using mobile sections of links instead of fixed for analysis purposes. Mobile sections avoid this problem by shifting a constant length along the roadway.

FHWA (1981) has identified the link node/nodal method acceptable for use in all areas, particularly urban, suburban, and rural highways. The workload requires developing, maintaining, and updating link/node numbers in maps and files, with funding required for the development of the mapping. Mapping and drafting equipment are also required to support this method.

Several advantages and disadvantages have also been outlined by FHWA (1981). A large advantage of this system is that it is easy to understand. It also has minimal time requirements and funding needed for start-up. FHWA (1981) also points out this method is conducive to cross-referencing between other mapping methods and is very flexible for complex situations. The link node/nodal method works well for areas, such as interchanges, where other methods might be too hard to adapt. In terms of disadvantages, this method is hard to use in rural areas because several miles usually separate

intersections (typical nodes). Filing of node and link information can be cumbersome and difficult for use in identifying crash clusters. This method of locating crashes is also not convenient for police officers, who require training to use the system and are required to carry large logs of node numbers to conduct placement.

6.2: Route-km/Milepost

The route-km and milepost methods appear to be one in the same. The route-km method, identified by PIARC (2003), involves assigning individual route numbers to all sections of continuous roadway. On each roadway, a zero point is identified and all crashes are located as some distance from the zero point on that route number. Markers are placed to identify distances traveled from the zero point to aid in locating. PIARC (2003) has pointed out the route-km method can be difficult for use in rural areas.

The milepost method, identified by FHWA (1981), also locates crashes based on their distance from a zero point, which is aided by milepost markers. This method, locates its zero points at the beginning of routes, county lines, etc. Contrary to PIARC (2003), FHWA (1981) feels this method is most appropriate for rural and suburban areas. It has been identified as difficult for use in urban environments because of confusion created by numerous intersections (adjacent intersection can sometimes have the same milepost number). FHWA (1981) estimates the cost of this method as about 100 dollars per mile, which is associated with cost of installing the milepost markers. Manpower is required for maintenance of the makers and equipment is required for initial set up. The milepost method offers two key advantages. The first of these is that primary users easily learn this

method. The second is that highway users are also able to report crash locations since milepost markers are in numerical sequencing. A disadvantage of the milepost method is that any changes roadway length can cause inaccuracies in location. This method can also be confusing when concurrent routes exist because it becomes difficult to identify which milepost is part of which route. Finally, if milepost markers are spaced too far apart, it can cause errors in reporting.

6.3: Reference Point

The reference point method, identified by FHWA (1981), involves using fixed and easily identifiable objects as reference markers from which the locations of crashes are measured. An example of a reference point is a railroad crossing. Signs are placed at intervals to aid in locating and contain jurisdiction information.

FHWA (1981) has identified the reference point method as good for use in rural and suburban areas, and bad in urban. They state it is difficult for use in urban areas because intersections are spaced too closely and it is more convenient to use street names. It has also been identified as a poor choice for developing areas. Manpower and equipment are required for sign maintenance and installation, and funding is necessary for developing, maintaining, and updating reference point inventory. An advantage identified by FHWA (1981) for the reference point method is that this system is unaffected by changes in route length. It is also easy to use on overlapping routes because signs still apply. The only disadvantage identified is that the accuracy of location is related to how close it is to a reference point.

6.4: Coordinate/Global Positioning System Based

Both the coordinate and global positioning methods rely on identifying a location based on specific coordinates. Both Ogden (1996) and the FHWA (1981) have identified the coordinate method for use. Ogden (1996) recommends having police officers identify crash locations in terms of horizontal and vertical distances from an intersection and having analysts use these measurements to place the location in a referencing system, such as GIS. FHWA (1981) recommends locating crashes with a unique set of plane coordinates, which are typically zeroed from the most southwestern corner of the state. Locations are identified as miles north and east of the zeroed location. The base of this coordinate system is usually compiled using U.S. Geodetic Survey topographical maps.

In their summary of the coordinate method, FHWA (1981) identifies its use as appropriate for all locations. Required funding is approximated as thirty dollars per mile and is used to develop the coordinate maps. Manpower is needed for assembling and maintaining the coordinate maps as well as for interpreting coordinate numbers. FHWA (1981) points out that large of using the coordinate method is it allows crashes to be permanently located in a two-dimensional plane. This location will be independent of future roadway changes. Another advantage of the coordinate method is it lends itself to mechanical plotting. A disadvantage of this method is it requires a lot of time to start up. It's also is extremely hard to estimate locations because coordinates need to be expressed as fourteen digit numbers due to map scaling. This method is also difficult to determine where inaccuracies exist.

The global positioning system (GPS) identified by PIARC (2003) relies on a series of satellites and a broadcast receiver that when used will give the location of a crash within five to ten miles of accuracy. Several advantages have been identified by PIARC (2003). The first of these is that it provides the most accurate coordinates of any system. Also, because coordinates are calculated by the receiver, it is free of human error. GPS systems can be connected directly to computers to receive coordinates, avoiding any transcription errors when entering into the report. PIARC (2003) also feels that when taking into account the benefits provided by using GPS units, the equipment worth the cost. GPS units can also provide benefits to emergency vehicles not associated with data collection. They can help emergency vehicles navigate quickly to the scene of the crash. Certain disadvantages are also associated with using GPS. The first of these is that a 'sky-view' and clear sightline are required for receivers to obtain the minimum four satellite signals for positioning. This can be difficult to achieve in densely populated areas, under trees, etc. GPS units provide locations based on 'x and y' coordinates. Not all referencing systems are based on x and y coordinates so algorithms are required to integrate the two. In terms of site use, GPS units are easily damaged and must also be turned on at the site for use. If officers forget to turn them on they must later return to the scene to run the equipment, as opposed to being able to write down the location from their office. Also, the accuracy of GPS units is only within five to ten miles. As opposed to other methods where placement error is usually along the roadway, GPS error can cause improper locating based on radii. In densely populated areas, such as urban environments, the location of a crash may be incorrectly placed at a nearby intersection.

6.5: Loran C-Base

The loran c-base method, where loran stands for long-range navigation system, has been identified by FHWA (1981). This method involves using receivers that measure locations based on the long-range navigation system. This system is available to 73% of the United States and is accurate within a quarter mile. This method is good for rural and suburban highways, but not for urban areas. Urban areas are undesirable because tall buildings can distort required radio waves. This method is one of the more expensive options, with receiver cost ranging between 425 and 5,000 dollars each (receivers are required for all police officers) and mapping costing about 200 dollars per 450 square miles to calibrate.

Advantages outlined by FHWA (1981) include accurate referencing coordinates that allow crash locations to be placed within about 50 feet of their true location. This method is also simple to use and does not require the installation and maintenance of field markers. A previously mentioned disadvantage of this method is that distortion to required radio waves sometimes occurs in urban areas. Another disadvantage is that while highway locations can be up to 50 feet accurate, the reference number used to obtain the true geographic location can have its own amount of error. Unless proper calibration has been performed, this reference number can contain a quarter mile error.

Chapter 7: Safety Audits

7.1: Introduction

Safety audits are unique in that they attempt to prevent crashes before they occur (proactive approach). Most methods employed today are reactive because they build strategy off of existing crash patterns. The 2002 version of Austroads defines a safety audit as, “A formal examination of a future road or traffic project or an existing road, in which an independent, qualified team reports on the projects crash potential and safety performance” (PIARC, 2003, pg 128). Ogden (1996) points out that safety audits are effective because they both remove design elements at the planning stage that could result in crashes as well as investigate already built designs to see if things need to be added to mitigate crash producing potential. The goals of the safety audit process, as outlined by Ogden (1996), include: minimizing crash potential and severity; reduce needed post-construction remedial measures; reduce lifetime project costs; increase engineering awareness of safety considerations related to the planning, design, construction, and maintenance stages of projects. According to Ogden (1996), the existing procedures allow unsafe elements of road design to be implemented in projects. Requiring the use of safety audits prior to project approval should greatly improve project safety.

7.2: Stages/Types

Austroads (2002) has identified four main safety audit types for different stages in project development, including: feasibility study, preliminary study, detailed study, and pre-

opening (PIARC, 2003, pg 129). These stages correspond well to those identified by Ogden (1996), which are the feasibility, draft design, detailed design, pre-opening, and in-service evaluations.

Audits can be run on existing roads to detect safety problems before crashes accumulate. Authorities sometimes hesitate in using this method because of corresponding legal responsibilities. If safety deficiencies are identified and a crash occurs from that deficiency before it can be repaired, jurisdictions fear a question of responsibility will be brought forth. According the PIARC (2003), however, this is an unjustified fear. For road sections exceeding 60 miles, Ogden (1996) has recommended a two-part investigation. The analysis starts with an overview of the entire segment to identify specific areas of deficiencies while the second part follows up with a detailed investigation of those deficient areas. Ogden (1996) has also pointed out that select authorities are now requiring safety audits at the proposal stage for all commercial and residential developments. The audit is to include comments on peak congestion periods, pedestrian and bicycle movements, driveway locations, etc.

7.3: Details

There are several details concerned with safety audits that need to be attended to. The first detail, pointed out by both PIARC (2003) and Ogden (1996), is that auditors are required to be independent of the projects they review. This means they are not to have any prior work relation to the projects development or success. This is important to eliminate biases. PIARC (2003) also stipulates that auditing should be done by a group of

individuals with diverse specialties. These specialties should include planning, traffic engineering, vehicle dynamics, human factors, etc.

PIARC (2003) has put together a group of details that they feel needs clarifying with regards to safety audits. The first of these items, and already been previously touched on, is the idea of auditor independence. Clear standards for what constitutes an independent party need to be issued. Also needed is a way to assess whether an individual is qualified to be an auditor. Legal issues surrounding audited works need to be clarified and an evaluation process needs to be determined to assess the success of the audit. PIARC (2003) suggests a cost/benefit comparison. The idea of an audit database has been suggested to help people learn from one another about defects. And on an international level, the idea of a universal checklist and audit procedure for use in developing countries has been mentioned.

7.4: International

On an international level, PIARC (2003) has identified several countries where safety audits have been introduced, including Australia, Canada, Denmark, England, and New Zealand. PIARC (2003) also points out that the majority of these nations have developed their own safety audit manuals. Continuing the topic of international success is Ogden (1996), who points out that in the UK they have discovered that up to 1/3 of the crashes experienced at individual projects have potential for prevention with safety audits.

7.5: Benefits

Several benefits have been associated with use of safety audits. Austroads (1994) [Ogden (1996)] has pointed out that with the use of safety audits, reductions can be seen in the number and severity of crashes. Austroads (1994) [Ogden (1996)] also asserts that safety audits increase the importance of safety in the minds of engineers as well as reduces several costs. Cost reduction can be seen in bypassed need for improvements later on and in reduction of costs to the community in terms of crashes, disruption, and trauma. In terms of cost effectiveness, PIARC (2003) has pointed out that although safety audits typically account for less than 0.5% of a projects total cost, it will experience significant crash savings.

Chapter 8: Methods for Identifying High Risk Locations

8.1: 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.

8.2: 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.

8.3: Rates

8.3.1: 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.

8.3.2: 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: $[\text{Crash Frequency} \times 10^8] / [365 \times \text{AADT} \times \text{roadway section length}]$.

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).

8.3.3: 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.

8.4: 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).

8.5: 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.

8.6: 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.

8.7: Index

8.7.1: 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).

8.7.2: 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.

8.7.3: 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 loses its effectiveness. This method also requires significant knowledge in highway safety and human factors.

8.8: 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 Bayesian method, identified by PIARC (2003), is a method that 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 that 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 its complexity.

8.10: Accident 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).

8.11: 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).

8.12: 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.

8.13: 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.

Chapter 9: High Risk Location Considerations

9.1: Statistical

Statistical analysis is often required to determine whether values are ‘significant’, or the result of chance. Graham et. al. (1975) suggests using statistical tests, called number-quality-control or rate-quality control techniques, to determine whether site values are significantly different from thresholds or averages. Ogden (1996) recommends using Poisson’s distribution to evaluate observed changes in crash trends. PIARC (2003) supports this by pointing out that the random nature of crashes causes them to follow this distribution. Ogden (1996) points out that changes resulting from chance can sometimes occur because of fluctuations in traffic flow. PIARC (2003) also recommends using statistical tests and confidence intervals to determine the reliability of analytical results.

9.2: International

In his book, Ogden (1996) sites findings from Zeeger in 1982 for usage of identification techniques for high crash location within the United States. This information has been summarized in Table A- 1.

Table A- 1: High Crash Location Identification Technique Usage in the U.S. (1982)

Analysis Technique	Percent Use on Major Roads	Percent Use on Minor Roads
Crash Frequency	89%	73%
Crash Rate or Quality Control Rate	84%	50%
Crash Severity	65%	45%

Ogden (1996) has also provided information on techniques used in the United Kingdom (not including London Boroughs). These findings, originally published by Silcock and Smith in 1984, are summarized in Table A- 2. In this table, the ‘multi-factor’ approach represents weighing different components however seen fit to analyze locations.

Table A- 2: High Crash Location Identification Technique Usage in the U. K. (1984)

Analysis Technique	Percent Usage by Authorities
Crash Frequency	74%
Crash Frequency (Weighted by Severity)	6%
Crash Rate	4%
‘Multi-Factor’	13%
Subjective Methods	11%
Other	6%

Ogden (1996) has also provided information on Australia. Australia relies primarily on crash frequency to identify high crash locations at intersections. For identifying high crash locations on road segments, Australia uses methods similar to prediction models, which evaluate the difference between the expected crash number and experienced to find locations with the most room for improvement. Ogden (1996) also mentions that several jurisdictions within Australia are starting to implement means to evaluate economic benefits on routes as well.

9.3: Treatment Strategies

9.3.1: General

There are several different approaches available to treating hazardous locations throughout the jurisdiction. Most often, organizations use methods that are directed at single site or route segments. Methods are also available known as mass action and area wide studies.

9.3.2: Site

PIARC (2003) defines site treatments as those occurring at locations less than 400 meters in diameter and route lengths between 300 and 500 meters. Ogden (1996) extends this definition to also include road features, such as bridges. Ogden (1996) points out that treatments for sites yield higher rates of return as opposed to the other methods because the treatment is less diffused.

9.3.3: Route

Ogden (1996) identifies route studies as those that look at segments of roadway between one and ten kilometers long. PIARC (2003) does not but a lower bound on roadway segment lengths, but says that segments should be less than 25-30 kilometers.

9.3.4: Mass Action

Mass action studies, according to PIARC (2003), involve the review of all or part of a jurisdiction's roadway network. A certain crash type is identified throughout the network,

for which a reliable mitigation has been developed, and then the treatment is applied throughout the jurisdiction. Locations selected for application should have high crash numbers related to the selected deficiency.

9.3.5: Area

Area studies, according to Ogden (1996) and PIARC (2003), are those that evaluate portions of a roadway network. Ogden (1996) defines the size of these portions as five square kilometers or greater. Ogden (1996) points out that when choosing an area for study, it is important to verify that it is approximately uniform and homogeneous in terms of its land use, density, and street configuration. Examples of areas for study, supplied by Ogden (1996), are commercial or residential areas.

9.4: Analysis Period

9.4.1: Considerations

When selecting an analysis time period, there are several factors that should be taken into consideration. One consideration, highlighted by Ogden (1996), is cost. Larger time periods require more additional analysis and computer storage. Ogden (1996) also brings up the concern of discontinuities. Selected time periods need to be checked for any changes in definitions that may have occurred. If the definitions of crash type, severity type, etc have been changed during the analysis period, then the data is no longer comparable. Both Ogden (1996) and NCHRP (2003) have highlighted the need to check for environmental changes during the selected analysis period. These include changes to roadway geometry, traffic growth, etc. PIARC (2003) and Ogden (1996) both point out

that it is best to use full years when selecting analysis periods in order to avoid biases that can be created by seasonal fluctuations. It is important to select an appropriate analysis period for each project because they greatly affect the outcome of studies (PIARC, 2003).

9.4.2: Long Analysis Periods

Long analysis periods can be good because they incorporate a larger supply of data. As Ogden (1996) points, this is especially important for analysis of hazardous areas to make sure there is a large enough sample size available. However, problems can also arise when analysis periods are too long. According to PIARC (2003), if the analysis period is too broad the picture may not adequately display the current crash trends because it includes the time period before it became an issue.

9.4.3: Short Analysis Periods

Ogden (1996) points out that shorter analysis periods can be advantageous because they allow problems to be detected earlier. Ogden (1996) also points out that they provide benefits when used on routes. Because route analysis involves combining several sets of data for different locations, shorter time periods allow quicker achievement of precision. However, it is also important to make sure that analysis periods are not allowed to become too short. As PIARC (2003) points out, as analysis periods start to become shorter, they lose statistical accuracy.

9.4.4: Recommended

Throughout the research process, information has been collected on recommended time periods to use for analysis. These findings have been summarized in Table A- 3.

Table A- 3: Recommended Values of Analysis Periods

Group	Recommended Analysis Period
PIARC (2003)	3 years. Based on study performed by May (1964)
Ogden (1996)	3 years. This is the time period typically used in the U.S. (reported by Zeeger) and in the U.K. (reported by Silcock and Smyth). Ogden (1996) also places an upper bound of 5 years on analysis periods.
NCHRP (2003)	Range of 1-3 years.

Ogden (1996) has pointed out that an analysis period of five years is the most statistically reliable because its corresponding sample size is large enough and it provides the ability to ‘smooth’ out short term fluctuations. Ogden (1996) also highlights an idea provided by Zeeger, known as ‘dual time periods’. Dual time periods entail running studies using both 1 year and 3 year analysis periods at a single location.

Chapter 10: Problem Diagnosis at Hazardous Locations

10.1: Site History

When analyzing a location, it is a good idea to gather information on the site's history.

PIARC (2003) has pointed out that gathering site history information can save money on the project because it prevents work duplication. Site history can also highlight any previous problems (PIARC, 2003). PIARC (2003) has suggested the following locations for gathering information:

1. Databases: Databases can provide information on the site's previous crash history, traffic volumes, geometry, traffic controls, etc.
2. Existing Photos and Videos
3. Previous Technical Studies and Reports: These can provide results of previous traffic-operations tests, maintenance or network updates, problems and their mitigations, etc.
4. Co-workers: Check to see if anyone else has past experience at the location.
5. External: Check to see if any complaints have ever been filed for the location.

Gathering information from these sources should provide a good starting point for further investigation.

10.2: Site Observation

10.2.1: General Information

Site observations are valuable for many reasons. First, they provide an opportunity to observe traffic operations. To maximize the benefit of the experience, PIARC (2003) has suggested scheduling site visits during conditions that may have contributed to the crash statistics. For example, if crash statistics show increased danger during the p.m. peak hour, schedule the site visit at this time. Site visits can also provide information on roadway geometry and driver behavior.

PIARC (2003) points out that site visits can also be used to identify problems with the location. PIARC (2003) suggests checking for differences between the site and applicable standards or common practices. They also point out that it is good to monitor driver behavior to see if driver expectancy and limitations are considered in the design. PIARC (2003) also suggests checking for any forms of roadway incoherence. Aside from identifying new problems, site visits can also solidify theories developed before the visit (PIARC, 2003).

Photos and videos can also be taken during site visits. PIARC (2003) has supplied a few helpful tips to remember when taking photos. First, it is best to take photos at constant intervals and for each direction of travel. Second, when taking photos, position the camera to show the view a driver of a passenger car would have through the site. Finally, take front and side view photos to show the driver's line of sight at all stop lines. This allows for visibility checks. PIARC (2003) suggests conducting video recordings as the

analyst drives through the site. PIARC (2003) points out it is also a good idea to have the driver make comments along the way about the situations encountered.

10.2.2: Site Familiarization

Site familiarization, suggested by PIARC (2003), is conducted as one of the analysts drives through the site. During the drive through, PIARC (2003) points out it is important to maintain the same speed as the surrounding drivers and to travel the site from all directions provided. PIARC (2003) has provided several areas of problems to check for during site familiarization. First, analysts should check for dangerous roadway characteristics. An example of this would be poor sight distance. Analysts should also check for improper traffic operations. This includes large speed differentials, traffic conflicts, extreme delays, etc. The area should also be evaluated for unsafe driver behavior. Check for illegal maneuvers by drivers, tailgating, extreme or dangerous speeds, etc. The site should also be evaluated for violations or driver expectancy or overloads of driver tasks. Examples of roadway features that cause this are poor transition zones and multi-branch intersections. Also scan the site for coherence problems, like through traffic on local streets, or poor maintenance, such as faded pavement markings.

10.2.3: Detailed Observation

PIARC (2003) has identified several functions of the detailed observation. First, this stage is where the location is checked to make sure any past identified problems were successfully mitigated. This stage also finishes gathering ideas of potential problems and their corresponding solutions. This includes addressing any new problems that were

encountered during site familiarization. Detailed observation also includes time to assess whether typical problems discovered under similar environments are also potential contributors for this location.

During PIARC (2003)'s detailed observation stage, analysts should also check for compliance with standards and practices. PIARC (2003) suggests checking: land use; posted and operating speeds; horizontal and vertical alignments; available sight distance; cross-section; pavement/surface conditions and markings; the roadside environment; provided accesses and crossings; condition or road signs; provided lighting; and intersection control and layout. PIARC (2003) also insists the location be checked for sufficient maintenance, driver expectancy and tasks, and improper driver behavior.

10.2.4: Common Problems

PIARC (2003) has put together a list of common problems found in both rural and urban areas. In rural areas, key contributors are unsuitable geometric characteristics, poor transitions (between road segments), and poor control of frontage access. The geometric characteristics and frontage access are important to check because they impact speeds through the location. In urban areas, key contributors are conflicting maneuvers (intersections and accesses), poor safety for multimodal, and overloads of driver tasks.

10.3: Site and Road Categorization

10.3.1: Site Categorization

Site categorization is important to safety studies because, as PIARC (2003) points out, it helps to place context to the location. PIARC (2003) has shown that the maneuvers and features analysts consider dangerous and the point where the number of crashes experienced becomes disproportional to the expected value are both dependent on the site's categorization. Therefore, it is important to classify a location by its site category early in the investigation process so that it can aid in identifying problems and solutions (PIARC, 2003). Furthermore, there are analysis tools that require information on the location's reference population, which is determined from the site categorization (PIARC, 2003).

National design standards are used to determine recommended characteristics of specific site categories. Site categories can be used to check locations for incoherencies and incompliance with design standards (PIARC, 2003). Site categorization can also point out typical problem areas (PIARC, 2003). Site categories should also be used when evaluating the appropriateness of mitigation strategies (PIARC, 2003).

10.3.2: Road Categorization

Similar to site categorization is road categorization, which is described by a locations primary traffic function, design speed, geometry, etc (PIARC, 2003). Functional classifications are a type of road categorization. Locations that are consistent with the descriptors of their road categorization should provide safe environments (PIARC, 2003).

10.4: Collision Diagram

Collision diagrams are used to identify predominant crash patterns experienced at high crash locations. These diagrams display information on: crash location, crash type, severity, intended and actual paths of each vehicle, etc [(PIARC, 2003) and (Graham et. al., 1975)]. If space permits, also include information on date and time, environmental conditions, lighting, number of severities, etc [(PIARC, 2003) and (Graham et. al., 1975)]. According to Graham et. al. (1975), these diagrams do not need be drawn to scale, but should show any traffic control devices. Graham et. al. (1975) also says it can be a good idea to show any vehicles or pedestrians that contributed to the crashes, but were not part of the collision. If there are too many crashes to fit on one collision diagram, Retting (2001) suggests creating collision diagrams for the location by crash type.

10.5: Spot Maps

Spot maps can be considered an extension of collision diagrams. As defined by Graham et. al. (1975), spot maps show a summary of crash locations for an entire city. They are used to identify locations within the city in need of special attention. Similar to collision diagrams, different colored markers are used to represent different crash types, severity levels, etc. Graham et. al. (1975) suggests using seven or less different types of markers to avoid overly confusing maps. Spot maps are typically made to represent one year, and Graham et. al. (1975) points out it is a good idea to display the previous year's map next to the current. This helps identify trends within the city.

10.6: Tables

Tables can be used to evaluate contributing factors to crashes. Two forms of tables have been identified by PIARC (2003): crash summary tables and crash comparative tables.

10.6.1: Crash Summary Tables

Crash summary tables are used to detect recurring contributing factors. They typically display characteristics for each listed crash, including: date, severity, crash type, surface condition, etc.

10.6.2: Crash Comparative Tables

Crash comparative tables are used to compare crash patterns at a specific site with those experienced at similar locations. These tables help to identify irregularities and aid in estimating improvement potential. To verify sites are comparable, evaluate the traffic operations and geometric characteristics of the control locations with the site under review.

10.7: Traffic Data

Traffic data is often used to aid in location evaluation. Graham et. al. (1975) has suggested several types of data collection techniques to aid in evaluations. These, along with a table of studies provided by FHWA (1981), are provided below.

10.7.1: Volume Counts

Graham et. al. (1975) suggests collecting information on volume. For intersections, Graham et. al. (1975) suggest evaluating entering volume and turning movements during the peak and non-peak periods. For roadway segments, they say to perform directional counts along with an analysis of vehicle classification.

10.7.2: Speed Studies

When speed is a possible contributing factor to crash trends, Graham et. al. (1975) recommends speed studies should be performed. According to Graham et. al. (1975), these studies analyze available sight distance at intersection approaches to determine the safe entering speed. Once done, they suggest comparing these values with the location's speed limits or the 85th percentile speed from data obtained at the site.

10.7.3: Condition Diagram

According to Graham et. al. (1975), condition diagrams provide pictures of the site characteristics and are usually drawn at either 1"=10' or 1"=40 ft' scales. They point out that these pictures include physical characteristics, traffic control devices, and regulations of the site.

10.7.4: Conflict Analysis

According to Graham et. al. (1975), conflict analyses highlight evasive actions taken by drivers at the site to avoid collisions. Graham et. al. (1975) points out that the frequency and types of evasive actions experienced can provide information on the crash situations.

10.7.5: Warrants

Graham et. al. (1975) points out that when analyzing a site it is usually a good idea to compare the existing conditions to those required by the MUTCD to warrant the signal controls present. They also say to evaluate whether additional traffic control devices are warranted. If they are, Graham et. al. (1975) says to assess whether their introduction to the site would be beneficial.

10.7.6: Studies

FHWA (1981) has also provided a list of traffic operations based studies, follow-ups to the crash-based studies, which can be used at high crash locations. These studies are used to determine causes of identified defects at the location and can be seen in Table A- 4.

Table A- 4: Operations Based Studies from FHWA (1981)

Study	Summary
Safety Performance Studies	Identifies operational and/or environmental inadequacies of highway facilities by performing field observations.
Volume Studies	Assembles traffic volume, turning movement, pedestrian movement, and lane distribution information. Provides information on exposure conditions.
Spot Speed Studies	Used to determine speed distributions. Use when high speed or differentials may be contributors to crash statistics.
Travel Time and Delay Studies	Gives time estimates for traversing roadway segments and any encountered delays. Use when congestion is a possible contributor to crash statistics.
Roadway and Intersection Capacity Studies	Estimates the location's ability to handle current or future traffic demands. Use when congestion is a possible contributor to crash statistics.
Traffic Conflict Studies	Evaluates evasive maneuvers to avoid potential collisions at the site. Possible indicator of crash potential, although not a defined relationship.
Gap Studies	Measures gaps between successive vehicles. Use to evaluate traffic mergers.
Traffic Lane Occupancy Studies	Uses vehicle lengths, volumes, and speeds to evaluate facility operations. Use when congestion is a possible contributor to crash statistics.
Queue Length Studies	Measure of intersection performance. Use when congestion is a possible contributor to crash statistics

NCHRP (2003) has also identified travel time and delay studies as useful when investigating locations. NCHRP (2003) points out that increased travel time and/or delays

create driver frustration, which can increase the crash experience. NCHRP (2003) also recommends use of traffic access studies to determine whether appropriate access has been provided to and from sites. Inappropriate access locations can cause vehicle stacking and erratic maneuvers.

10.8: Environmental Studies

A list of environmental studies has been provided by FHWA (1981) to gather information about roadway physical features. These studies are provided in Table A- 5.

Table A- 5: Environmental Studies from FHWA (1981)

Study	Summary
Roadway Inventory Studies	Survey of the roadway physical features. Recommended for use in all situations.
Sight Distance Studies	Assesses available sight distance at the location.
Roadway Serviceability Studies	Evaluates pavement surface at site.
Skid Resistance Studies	Uses ASTM standards to determine whether sufficient traction is provided between road surface and tires. Use when crash statistics identify wet-weather as a contributor.
Highway Lighting Studies	Identifies inconsistencies between the site and lighting design standards. Use when crash statistics identify darkness or nighttime as a contributor.
Weather Related Studies	Checks for increased hazard during specific weather conditions. Examples are fog or ice.

10.9: Additional Techniques

The following is a list of additional investigation techniques identified by FHWA (1981).

Table A- 6: Additional Studies from FHWA (1981)

Study	Summary
School Crossing Studies	Uses pedestrian volumes and delays, road widths, and traffic control device information to assess the safety of facilities surrounding schools. Accounts for level of understand experienced by students.
Railroad Crossing Studies	Assesses safety of at-grade crossings.
Traffic Control Device Studies	Uses signal warrant studies, stop-yield sign studies, and law observance studies to assess safety of current traffic control devices.
Bicycle Studies	Investigates bicycle facility capacity, speeds, volumes, sight distances, traffic control devices, etc to assess level of safety and operation.
Pedestrian Studies	Uses pedestrian volumes, crossing delays, traffic control devices, pedestrian related conflicts, etc to assess level of safety and operation.

Chapter 11: Countermeasure Selection

11.1: Estimating Benefits and Costs

For most of the economic based countermeasure selection procedures, it is necessary to estimate the benefits and costs associated with different countermeasure options. Ogden (1996) defines the benefit of a project as the amount of money saved as a result of the project's ability to reduce crash occurrences and/or severities. To estimate the reduction in crash occurrences and severities, PIARC (2003) suggests using a national database that can provide typical outcomes of different types of countermeasures. Once the crash change has been estimated, these values need to be turned into dollar amounts. To do this, PIARC (2003) suggests using an economic value, set in place at a national level, to estimate the benefit obtained by the reduction of each type and severity of crash. PIARC (2003) says these economic values should be updated each year. According to PIARC (2003), project costs should include the costs associated with designing and building the project. Ogden (1996) says that any operational or anticipated maintenance costs should be included in the costs calculation and deducted from the benefits estimate. All calculations need to take into account the project service life, as pointed out by PIARC (2003), and economic inflation, as pointed out by Ogden (1996).

11.2: First Year Rate of Return

The first year rate of return is a method identified by both PIARC (2003) and Ogden (1996). PIARC (2003) defines the first year rate of return as the benefits incurred by a

project during its first year of operations, divided by the total capital costs, and expressed as a percentage. Their definition of 'benefit' is the dollar value of crash savings minus any operational costs. PIARC (2003) points out that this method is useful in prioritization because it is easy to calculate mathematically and it ignores project performance after the first year. However, PIARC (2003) states that this method is not useful for projects where high fluctuations of crash statistics and traffic volumes are expected on an annual basis. Ogden (1996) brings forth another point of view, stating that the first year rate of return method can be used for prioritizing projects but is generally invalid for use in economic terms. Ogden (1996) also points out that this method is utilized frequently by the United Kingdom, who claims its use to be reasonable because benefits of a project are difficult to assess past the first year.

11.3: Net Present Value

Both Ogden (1996) and PIARC (2003) define the net present value as the difference between the discounted benefits and costs of a project over its service life. The term discounted means to evaluate the benefits and/or costs of the projects during the future period they occur in and then translate that monetary value to present worth. PIARC (2003) and Ogden (1996) state that any project with a positive net present value (meaning the benefits are larger than the costs) can be considered worth while. Also, the larger the net present value, the more worth while it is. Ogden (1996) states that the project with the highest net present value is the one most appropriate for selection. Ogden (1996) state the net present value method is one of the best for use in economic evaluations for the following reasons: its results are easy to understand; it is less likely to experience room

for error from assumptions; it provides a means for ranking projects without additional calculations; and it is easily calculated.

11.4: Net Present Value/ Present Value of Cost Ratio

This method, identified by PIARC (2003), is a modification of the net present value calculation. In this method, the net present value is calculated as earlier described, but is then divided by the discounted cost of the project. PIARC (2003) points out that this extra step in analysis eliminates the tendency for net present value calculations to prioritize high cost projects. PIARC (2003) prefers this calculation to the traditional net present value method, especially when used to rank projects.

11.5: Benefit-to-cost (B/C) Ratio

According to FHWA (1981), the benefit-to-cost ratio is calculated by dividing the savings incurred from resulting crash reductions by the project cost. FHWA (1981) says that when this ratio is a positive value, the savings received are higher than the cost input, making this a worthwhile project. They say to determine these two input value, information is needed on the initial costs of the project, its net operating and/or maintenance costs, the annual safety benefits, a dollar value to assign to each unit of safety achieved, the project service life, the project salvage value, and the interest rate. FHWA (1981) says this project requires engineers who are experienced in safety and economics, and relatively little funding.

FHWA (1981) states that this method is good to use when severity needs to be considered for measures of effectiveness. They say it also is a straight forward way to determine the best mitigation. Despite its advantages, FHWA (1981) says economists debate over whether it adequately accounts for the increased cost of more sophisticated projects. According to FHWA (1981), this method also places an estimated dollar value on human loss and then relies on the validity of this number for decision-making.

11.6: Benefit-to-Cost Ratio/Incremental Benefit-to-Cost Ratio

Ogden (1996) states that the benefit-to-cost ratio should not solely be use to rank projects, and instead calculations should be taken a step further to determine the incremental benefit-to-cost ratio. To perform this calculation, Ogden (1996) says benefit-to-cost ratios greater than one should be put in ascending order. He says a comparison should be performed between each set of pairs, starting with the two lowest options. To perform this comparison, Ogden (1996) states the following equation should be used:

$$\frac{[(\text{benefit of project 2})-(\text{benefit of project 1})]}{[(\text{cost of project 2})-(\text{cost of project 1})]}$$

Ogden (1996) state that when the equation yields a positive value, project 2 is the better option, and when the equation yields a negative value, then project 2 should be thrown out of consideration. Ogden (1996) states this should be done until the entire list has been evaluated and only one project option remains. He states the remaining project is the best option. Ogden (1996) points out that this method can lead to ambiguous results and recommends use of the net present value method. One specific problem Ogden (1996) points out is whether to account for maintenance costs as an increase in project costs or as

a decrease in project benefits; both options lead to different results. Ogden (1996) says there is nothing to indicate which is the correct option.

11.7: Internal Rate of Return

According to PIARC (2003), the internal rate of return is the discount rate that would need to occur in order for the benefits experienced from a project during its first year of operation to be equal to the total project cost. PIARC (2003) points out that this method is not good for ranking projects. According to Ogden (1996), once the internal rate of return is calculated, it should be compared to the expected discount rate of the project. Ogden (1996) says that if the internal rate of return is greater than or equal to the expected discount rate, then the project can be considered worthwhile. Ogden (1996) says that when using internal rate of return for ranking projects, the incremental internal rate of return should be computed. Ogden (1996) points out that the internal rate of return method is nice because it is easily compared with yields from investments, making it easy for decision makers to relate with. However, Ogden (1996) also points out that the internal rate of return is difficult to compute and not always possible to find. He also points out that this method can be biased towards short-term effects.

11.8: Cost-Effectiveness Method

According to FHWA (1981), the cost-effectiveness method ranks projects based on the amount of money required to achieve a certain level of benefit. FHWA (1981) says that calculations of this measure requires information on: the initial project cost; annual

maintenance/operating cost; units used to determine effectiveness; annual benefit; project service life; net salvage value; and interest rate. They also say this method requires minimal funding and workers. FHWA (1981) identifies an advantage of this method is it doesn't assign a dollar value to the losses incurred from crashes, which are based on severity level. They say it also provides means to optimize the resulting benefits. According to FHWA (1981), a disadvantage of this method is the results it provides are hard to use for interpreting when improvements are justified.

11.9: Rate-of-Return Method

FHWA (1981) says this method is based on the assumption that a project's worthwhile can be evaluated based on the interest rate required to place its benefits at zero. They say it also assumes that the benefits achieved remain at a constant value each year. According to FHWA (1981), the project with the highest interest rate is considered the most beneficial option. FHWA (1981) says this method requires moderate funding and engineers familiar with economics. They also say this method has advantages in its ability to optimize the benefits incurred from mitigation selection and a calculation that is independent of assumed interest rates. A disadvantage identified by FHWA (1981) of this method is it requires a dollar value be assigned to human life. They say it is also difficult to interpret and requires iterations to determine the resulting interest rate.

11.10: Time-of-Return Method

This method, according to FHWA (1981), computes the time-of-return by calculating the project cost and dividing it by its annual benefit. FHWA (1981) says annual benefit can be computed using forecasting techniques based on previous completed studies, or other variations of economic analysis. They say the mitigation option with the lowest time-of-return is the best option. FHWA (1981) states that this method requires information on the crash types impacted by the mitigation, estimates of crash reduction by type, expected fluctuations in traffic volume from the mitigation, total improvement cost, and the total benefit estimated from the data analyzed for the years. They also state it requires low funding and minimal workers.

According to FHWA (1981), an advantage of this method is it identifies the time needed to pass the project benefits and costs to break even. They say it also provides a way to optimize the benefits received from mitigation. A disadvantage of this method, identified by FHWA (1981), is it requires a dollar value be assigned to crash severity. According to FHWA (1981), although this method results in a time calculation, it can be difficult to interpret its meaning since it does not account for project service life. Also, they say this method omits interest rates, annual maintenance costs, project service lives, and project salvage values.

11.11: Net Benefit Method

According to FHWA (1981), this method evaluates mitigations based on their net annual benefit, which is the difference between the calculated equivalent uniform annual benefit and the equivalent uniform annual cost. They say the optimum mitigation is the one with the greatest positive net benefit. To calculate this measure, FHWA (1981) says information is needed on: initial and annual costs; project salvage value, project service life estimates; the estimated amount of benefit for each improvement; and the interest rate. FHWA (1981) says this project requires minimal funding and workers.

Advantages of this method, identified by FHWA (1981), are its relative ease and ability to optimize benefits for each location. FHWA (1981) states that it also allows continued analysis with options that are mutually exclusive. According to FHWA (1981), a disadvantage of this method is it assigns dollar values on the severity resulting from crashes. They say it also prioritizes high cost projects over low cost.

Chapter 12: Countermeasure Evaluation

12.1: Monitoring Improvements

It is important to monitor the site after countermeasures have been carried out to gather immediate results on its outcome. PIARC (2003) has suggested that an appropriate time for monitoring begins after two months have passed from construction completion. This allows roadway users to adjust to the new roadway network. PIARC (2003) points out that monitoring not only indicates progress of the site, but it can also alert safety analysts of any negative and/or unexpected outcomes of a countermeasure. Monitoring also provides data that can be helpful when deciding whether to use a countermeasure for future projects (PIARC, 2003). Ogden (1996) asserts that collection of this data will improve the accuracy of future project predictions. Both PIARC (2003) and Ogden (1996) have shown that for monitoring purposes, it is not conducive to collect data solely on crash results. In order to obtain statistical reliability, crash data can take too long to collect and thus defeat the purpose of monitoring the site. Ogden (1996) sites a list of parameters to monitor given by Ward and Allsop (1982), which includes: number, type, and severity of crashes; crash distribution on road network; traffic flow; travel time; intersection turning movements; intersection delays; residential area access times and distances; route usage; and bus operations. PIARC (2003) suggests adding to the list of parameters measures which directly assess the targeted crash type reduction. The example given by PIARC (2003) is collecting skid data when the targeted crash type reduction was for crashes involving skids. Although monitoring of the site is important, PIARC (2003) points out it will not indicate the degree of improvement.

12.2: 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 conducting 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.

12.3: Accident-Based Evaluation

Since it is not economically feasible to conduct safety analyses on all completed projects, it becomes more crucial that the appropriate projects for analysis be the ones selected.

According to FHWA (1981), projects which justify selection are those with the highest probability of being implemented again in the future, were completed in the previous five years, and have sufficiently large numbers of accidents (to allow a reliable statistical analysis). However, if there are not enough accidents present at a project site to allow for an effective statistical analysis, FHWA (1981) says similar projects can be combined to increase available data. (This is known as an aggregate project evaluation).

Following accident-based evaluations, FHWA (1981) recommends that results be entered into an 'effectiveness data base'. According to FHWA (1981), this data base will be an accumulation of project evaluation results, including Measures of Effectiveness (MOE's), that can be used as the basis for future project development. FHWA (1981) says the effectiveness data base allows safety analysts to review previous mitigations at accident

sites similar to their own. They say the data base should include average accident rate reductions for each project site to demonstrate its accident reducing capabilities. FHWA (1981) states that the data base can also be used to create a final output of accident-based evaluation summaries for each project in terms of changes in MOE's, their statistical significance, and its cost-effectiveness.

A two to three year period of data collection, before and after the project implementation, is recommended by FHWA (1981). They say these analysis periods should be selected at points when no significant changes in geometry, traffic, or traffic control devices have taken place other than the improvement project. FHWA (1981) says the earlier an analysis period is started, the faster information becomes available to indicate whether it is serving its purpose.

For each improvement project, FHWA (1981) states a list of study objectives should be compiled to qualify the end results. They say these study objectives are analyzed in terms of project effects on total accidents, fatal accidents, personal injury accidents, and property damage accidents, and are quantified in terms of selected MOE's. MOE's are expressed in terms of frequency, rates, proportions, and/or ratios. FHWA (1981) shows that the rate-related MOE's are based on traffic volumes and exposure data, which are expressed by number of vehicles or vehicle-miles traveled. According to FHWA (1981), often, the analysis of MOE's requires obtaining data from the project site after implementation. In such cases they say it is important to make sure data collection and evaluations take place after enough time has passed for traffic to adjust to new

conditions. To analyze MOE's for after project implementation, FHWA (1981) says an expected value is generated and compared to an actual value to determine a percent change. They say the percent changes are then used to qualify the effectiveness of the project.

According to FHWA (1981), plans for evaluating highway effectiveness and study objectives include: before and after study with control sites; before and after study; comparative parallel study; and before, during and after study. They say the before and after study with control sites uses percent changes in the MOE's, evaluated before and after project implementation, and compares them with selected control sites. FHWA (1981) shows that using a control site can account for natural fluctuations in MOE's, which are not attributable to project implementation. They select control sites that share similar accident patterns to the project site. According to FHWA (1981), although accident frequencies and severities are compared, it is also important to compare other site characteristics to make sure that similarities in frequencies and severities are not from chance. FHWA (1981) says things that are also compared between sites include horizontal and vertical alignment, number of lanes, and traffic volumes. They say the before and after study is based on the before and after study with control sites method, but is used when appropriate control sites cannot be identified. According to them, other than this difference, all methodology is identical. They also say the before and after study, without control sites, is considered a fairly weak analysis approach and is very rarely recommended.

Another variation of the before and after with control sites, identified by FHWA (1981), is the comparative parallel study. This study they identified relies on MOE comparison between control and project sites after project implementation. Although good, FHWA (1981) says this study is not considered as effective as the before and after with control sites method. They show that a fourth option is the before, during, and after study.

According to them, this study determines MOE's based on project site data obtained before, during, and after project implementation, and is good for evaluating temporary projects.

FHWA (1981) says statistical analysis is also key in accident-based evaluations. They say it is used to determine whether changes in MOE's resulted from project implementation or are the result of other factors. The Poisson Test is recommended by them for establishing the significance of changes in MOE's. FHWA (1981) says confidence levels will need to be established for statistical analyses, and are usually based on project costs. They identify that this means large-scale projects will have a higher confidence level than smaller-scale projects.

FHWA (1981) says an economic evaluation of the project will also need to be conducted. Two of their suggested methods include the benefit/cost ratio and the cost effectiveness. According to FHWA (1981), the benefit/cost ratio compares the decreases in accident frequency and/or severity from the project to the cost of project implementation. FHWA (1981) says the cost effectiveness method evaluates project success by looking at the cost

to prevent a single accident or accident type, based on accident reductions from the project.

12.4: Non-Accident-Based Evaluation

FHWA (1981) says the non-accident-based evaluation is helpful to evaluators because it provides an immediate indication of project effectiveness. According to FHWA (1981), the non-accident-based evaluations look at the chain of events typically leading to accidents and rely on a comparison on before and after MOE's. They say the MOE's provide information regarding project impact of traffic performance, project effectiveness (when looking for a quick indication), the presences of factors affecting the post-accident experience, and the relationship between accident and non-accident measures. However, FHWA (1981) says the non-accident-based evaluation should not be used as a substitute for the accident-based evaluation because no proven relationships have been established between reduction of non-accident-based MOE's and accident-based MOE's. FHWA (1981) says the results from this evaluation should also be entered into the 'effectiveness data base' to aid in future project development.

According to FHWA (1981), non-accident related MOE's include traffic conflicts, auto-pedestrian conflicts, vehicle speeds, traffic control violations, and erratic vehicle maneuvers. FHWA (1981) shows that data for these measures can be obtained through spot speed studies, travel time and delay studies, intersection delay studies, and traffic conflict studies. They say the non-accident-based project evaluations generally require the gathering of more field data than the accident-based. Also, they show that the sample

size of this data is dependent on the selected level of confidence to be used in statistical analysis.

FHWA (1981) says that alternatively to accident-based projects (which can only be statistically analyzed using the Poisson Test), statistical analysis for the non-accident-based projects can be done with the chi-square test, t-test, z-test of proportion, or the f-test. FHWA (1981) has said that statistical analysis is necessary to determine whether fluctuations in MOE's can be attributed to project implementation. They say fluctuations in MOE's are reported in terms of percent changes between calculated anticipated MOE's and actual MOE's after project implementation. For non-accident-based evaluations, they say the MOE's can have either positive or negative reductions.

FHWA (1981) asserts that an economic analysis should also be conducted for this evaluation to help determine whether project expenditures were justified. Their recommended method (and only approved method) is the cost-effectiveness evaluation. According to FHWA (1981), this method evaluates the dollars spent for each non-accident measure eliminated.

12.5: Program Evaluations

FHWA (1981) has recommended program evaluations to assess either completed or ongoing safety programs. They say programs should be evaluated based on their effect on total accidents, fatal accidents, personal injury accidents, property damage accidents, etc. FHWA (1981) says changes in these areas are typically measured using accident

frequencies, severity rates, and proportions or percentages. FHWA (1981) points out that program evaluations are considered beneficial because they can point out existing deficiencies and lead to improved project performance while the project is still in process. For programs consisting of many sub-projects at multiple locations, they say it is often convenient to group the sub-projects for evaluation based on similar project and location characteristics.

Similar to other evaluation methods, the use of control sites is recommended by FHWA (1981) for program evaluations. FHWA (1981) says control site selection is based on similarities in accident and exposure data for the location of analysis and potential control sites. When using exposure data, they say it is crucial that it be gathered during the same time period as the accident data. FHWA (1981) has shown that accident and volume data are in turn the most common forms of data used for program evaluation.

FHWA (1981) says measures of Effectiveness (MOE's) should be used to compare the before and after periods of program implementation for the project and control sites. TO do this, they say post-implementation MOE values are forecasted and compared to actual MOE values, obtained annually. They say the percent difference between expect and actual values of MOE's is used to rate the effectiveness of the program or program subset. New challenges to ensuring accurate analyses of MOE's, according to FHWA (1981), are created from the nature of programs to continue for many years. FHWA (1981) warns that changes in MOE's can result naturally over time and supply misleading results. They say regression of the mean and random data fluctuation can also threaten

the validity of the MOE's. To ensure the analyses lead to meaningful project results, a statistical analysis is also encouraged by FHWA (1981).

According to FHWA (1981), statistical tests should be selected for each program objective and corresponding MOE to evaluate whether changes are statistically significant. The possible tests recommended by them include: Poisson Test, Chi-Square Test, t-Test, Z-Test, and F-Test. They also recommended that an economic analysis be performed using either the benefit/cost ratio technique or the cost-effectiveness technique. FHWA (1981) says economic analyses should be conducted based on the agencies comfort in assigning dollar values to accident outcomes, availability of cost data, and the types of MOE's used.

Chapter 13: Conclusion

The literature review compiled here contains a plethora of information regarding many areas of safety analysis. As a result of its broad area of focus, it leaves the question of which part to delve into more. Using this information, an area of special interest will be selected for further development during completion of the thesis.

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