Municipality of Anchorage

Guide for Conducting Intersection Safety Reviews

July 2003

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1 Introduction

What is an Intersection Safety Review?

An intersection safety review is a structured examination of an intersection from a safety perspective with the intention of increasing the level of safety by reducing crash frequency and severity. The general process includes identification of crash trends and patterns, hazardous elements, inconsistencies and other safety concerns, and the generation and selection of crash countermeasures and other remedial safety initiatives.

Goals and Objectives of an ISR

The goal of an ISR is to identify appropriate modifications to intersection planning, design, construction, operation and maintenance that will improve the safety performance of an intersection for all road users. The "appropriateness" of modifications, as suggested in the above goal, is unique for each situation and cannot be universally defined. The section titled “Context” will provide more discussion on this matter. ISRs are typically initiated through the monitoring of the safety performance of the network (i.e. a crash prone location program) and the findings can used to tie into the planning, design construction, etc,,, of an intersection.

The "safety performance" of an intersection is defined by the crash record. Therefore, the objectives of an ISR are to:

- Reduce the crash frequency of an intersection;
- Reduce the exposure-based crash rate of an intersection;
- Reduce the severity of crashes at an intersection; and
- Eliminate or mitigate elements of the intersection that are reasonably known through past research and experience to be "hazardous", whether or not they are currently causing crashes.

Objective and Scope of This Guide

This *Guide for Conducting Intersection Safety Reviews* has been developed to introduce a uniform understanding of safety engineering design and operating practices amongst Municipality of Anchorage (MOA) staff in the Traffic Department. It reflects industry 'best practices' in road safety engineering.

As such, the objectives of this guide are to:

- Promote uniformity in the undertaking and documenting of safety reviews;
- Provide a basic framework that will encourage the user to understand the safety implications of various planning, design, operation and maintenance choices;
- Outline a logical and traceable decision-making process; and
- To provide the MOA with a reasonable and defensible method of dealing with safety concerns and issues.

The purpose of the guide is not to determine when an ISR should be carried out, but to outline the ISR process once the decision has been made to undertake a review.

The procedures/information contained in the body and appendices of this document are necessarily general, as they cannot cover all site-specific aspects of a safety

review. Where available, references to other sources of pertinent information/ research have been included for each element of the procedure. The list of potential references is not exhaustive. It merely directs the user to many of the more popular and useful documents on road safety.

Content

Formatted as a procedural manual, this guide provides instruction in:

- Office preparations for safety reviews;
- Field investigations;
- Diagnosis of safety concerns;
- Selection of countermeasures; and
- Documentation.

This guide is not intended to replace any of the existing investigative or design procedural documentation. Instead, it is to act as a companion to all such documentation. The content and spirit of these safety-engineering practices could be integrated into the MOA's everyday investigative and design processes.

It is also intended that this Guide be used in combination with other industry documents related to safety in traffic and transportation engineering. An increased familiarity with these associated documents is strongly encouraged for all traffic safety practitioners in the MOA Traffic Department.

Context

It needs to be stressed that the term 'safe' is relative and must be placed in the proper context. A completely safe road is one in which no crashes have been, or are expected to be, observed. As long as roads are used by pedestrians, bicyclists and motorists a "safe" road is unachievable. The myriad of environmental conditions that may be encountered, including that of the road itself, the motorists, and the vehicles, simply make it impossible to ensure that no crashes will occur. This being the case, it is accepted practice to acknowledge that there are varying degrees of safety that are based on the prevailing conditions. The goal of the process, therefore, should be to provide intersections that are as safe as possible within all of the operational constraints.

The focus of this document is on safety, and solely safety. It is acknowledged that safety is one of many considerations that the Municipality of Anchorage needs to balance in the planning, design, construction, operation and maintenance of roadways, including, but not necessarily limited to, cost, environmental protection, congestion management, and community impacts. This report is focused on safety, with the anticipation that in general, the findings will be used as input to the design process, rather than as a requirement of design. The safety recommendations need to be considered in light of the various "trade-offs" associated with implementation.

The road safety knowledge base is continually being updated. Although this process is necessarily general, it is prudent for the Municipality to stay up-to-date on the safety research and to update this guide as required.

Definitions

The following terms are used frequently in conducting intersection safety reviews and have specific meanings as follows:

Conflict Study – A traffic conflict occurs when two or more road users approach the same point in time and space, and at least one road user takes successful evasive action to avoid a crash (Hamilton Associates, 1997). A traffic conflict study involves the observation and documentation of severe "near misses" between various road users. Conflict studies can be used to supplement crash data or to measure road user risk. A further description of conflict studies and their function can be found in Hamilton Associates (1997).

Conformance Check - A conformance check is an assessment of the roadway, signage, illumination, pavement markings and other associated physical and operating attributes to ensure they reflect:

- Current accepted guidelines and standards;
- Municipal policy, practices and directives; and
- Conditions at other similar/adjacent locations.

Countermeasures – are treatments identified as having the potential to *address one or more dominant crash types* currently being experienced at a location. The treatment may be infrastructure modifications, an operational change, new legislation, increased enforcement, or any combination of the above.

Evaluation Program – a means of evaluating the effectiveness of the *countermeasures* implemented. Included in the evaluation program is the need to review the measures undertaken to ensure they have been implemented as planned and have not manifested other safety or operational concerns.

Implementation Plan – a means of ensuring that the nature and urgency of the *remedial measures* are conveyed to the correct department/agency for consideration. Included in the implementation plan is the need to review the measures completed, to make certain they have addressed the initial safety concerns and that they have not manifested other safety or operational concerns.

Positive Guidance Review - Positive Guidance review is a process that uses an in-depth knowledge of human factors and the driving task to screen roadways for information deficiencies, expectancy violations, workload issues, environmental factors and operational scenarios that may potentially contribute to the occurrence of driver error and crashes.

A short "primer" on the PGR approach is included in **Appendix A** of this report. A detailed explanation of the PG process can be found in the User's Guide to Positive Guidance produced by the Federal Highway Administration.

Potential Hazards – identified deficiencies in safety, operations and/or positive guidance at a location that may or may not be contributing to a specific crash concern but through research is known to increase crash risk.

Remedial Measures – improvements that should be undertaken to correct/address

potential hazards associated with safety, operations and/or positive guidance. The measures may be infrastructure modifications, an operational change, new legislation, increased enforcement, or any combination of the above. Remedial measures are different from countermeasures in that countermeasures address existing crashes, and remedial measures address potential hazards.

Data Requirements

An ISR is an information and data intensive process that typically makes use of the following:

Core Data Requirements:

- Physical characteristics of the intersections
- Daily and peak period traffic volumes and turning movements;
- Traffic operational characteristics;
- The crash record; and
- Recent/planned changes to the intersection and its operation.

Supplementary Data Requirements:

- Traffic conflict data;
- Insurance claims and self-reported crash data;
- Additional traffic measurements such as speed studies, gap analysis, etc.;
- Stakeholder input; and
- Maintenance records
- Complaint logs
- Crash prediction models (if available).

The infrequent occurrence of crashes at a particular location, and the essentially random nature of crashes dictate a need for relatively large amounts of crash data for proper safety analysis.

In many instances all of the requisite data will not be available, and it may not be practical to gather the missing information.

It is always preferable to secure local data, statistics, and information for even subtle differences between jurisdictions may limit the applicability of using another road authorities data for comparison purposes. Should local data not be available, and it is impractical to collect it, then the following procedure should be followed:

1. *Crash Data and Crash Prediction Models*

For surrogate values relating to crash data and crash prediction models (CPMs) , find a jurisdiction that is similar to MOA and use data that they have assembled. Similarity should be judged by considering:

- Crash reporting requirements - self reporting, minimum reporting levels, etc.;
- Setting - urban, rural, suburban;
- Legislation - right turns on red, pedestrian priority, etc.;
- Current fleet - mix of passenger cars and heavy vehicles, vehicle safety standards, etc.;
- Driver population - demographics, graduated licensing programs, etc.; and
- Road standards - similar design guidelines, operating practices, etc.

The above list is not exhaustive and should be supplemented with other factors as required.

The preferred jurisdictions for "borrowing" crash statistics are, in decreasing order of preference:

- City of Juneau;
- City of Fairbanks;
- State of Alaska;
- Other municipalities in the United States with a similar population and setting;
- Other municipalities in Canada with a similar population and setting;
- Other States; and
- Other Canadian locations.

Generally it is *not* recommended that crash statistics from locations outside of the United States or Canada be used for comparison purposes.

2. Other Information Requirements

The ISR process requires information such as the societal cost of a crash, and countermeasure effectiveness. Again, if this information is not available, then it is appropriate to "borrow" information from another jurisdiction. Transferability of the information from one jurisdiction to the next should be based on similarity between important characteristics.

2 PROCEDURE

The following section describes the procedure for completing an ISR in the MOA. Not all of the study tasks need to be conducted for every study. The stakeholder consultation, the traffic conflict analysis, and the positive guidance review are optional tasks that may be needed in specific circumstances. The scope of the ISR for each individual project should be defined at the initiation of the study by the MOA.

Stakeholder Consultation

Each review should be initiated with notification of the study to all appropriate stakeholders. Internal notification could be accomplished through e-mail, inter-office correspondence or other applicable means. External contact will vary depending on the project scope/extent.

Staff should take care to include those parties who may not be immediately impacted by the study, but whose properties or interests may be impacted by the outcome of the investigation (e.g. adjacent property owners, nearby sources of pedestrians, nearby sources of persons with special needs, etc.).

This activity provides the opportunity to:

- Explain the purpose of the safety review;
- Solicit input from a diverse group regarding the study location, its operations and potential deficiencies; and
- Identify individuals that should be invited to actively participate in the review due to a site-specific concern or special knowledge of the location.

Office Review/Investigation

The purpose of the initial office review is to gain a *general understanding* of the characteristics of the location prior to investigating on-site. So that the field work is not focused on a particular safety/crash concern, detailed analysis of the crash/conflict data *may* be deferred until after the field investigation.

Since crash occurrence and severity are the primary metrics (foundation?) of safety, the crash analysis is the foundation of the ISR.

A systematic examination of the following items, as available/applicable, should be undertaken prior to the field review:

1. Traffic Operations

A. Operating Characteristics
It is important to construct a profile of the operational characteristics of the study site. Typically, this includes the following analysis:

- Annual change in traffic volume. This determines whether or not traffic volume patterns have been subject to fluctuation or significant growth in recent years.
- 24-hour volume distribution. This allows the analyst to determine the

peak hours of the day in terms of volume demand. This information is useful to correlate the hourly volume distribution with the hourly crash distribution. Separate 24-hour volume distributions may be required for weekday and weekend conditions, and for different months of the year at locations where there are significant seasonal variations.

- Vehicle classification distribution. At locations where the vehicle demand may contain significant proportions of heavy trucks or motorcycles, it is useful to survey and analyze the vehicle classification characteristics.
- Peak hour volumes. This data is essential for the analysis of operational efficiency (described below). The peak hour volumes for the various periods which are of interest should be tabulated or graphically plotted. As a minimum, this is typically done for the morning and afternoon peak hours. Midday and Saturday peak hour volumes may also be required, depending on the site characteristics.

At some locations, the traffic volumes for special hours should also be analyzed, for example hours related to school drop-off and pick-up periods. The peak hour volumes should consist of the turning and through traffic volumes per approach. Pedestrian and bicycle counts should always be included in the analysis of peak hour volumes.

B. Operational Efficiency

The traffic operational efficiency at the study site should be analyzed, as operational efficiency can have a direct bearing on the crash risk. The capacity and performance of study intersections should be quantified for each peak hour of interest, using measures such as delay (possibly represented by a level of service), volume/capacity ratios, and queuing for each turning movement and for the intersection as a whole.
This analysis is typically conducted according to the procedures of the Highway Capacity Manual (TRB, 2000). The analysis is typically assisted by commonly available commercial software.

Delays to drivers may increase frustration and lead to drivers taking risks. For example, drivers who have waited to turn left for several cycles of a traffic signal (at movements that are operating at poor levels of service) may accept inadequate gaps to make their left turns. The poor capacity performance of the left turn movement would then be identified as a possible explanation if a high proportion of left-turn opposing-through crashes is recorded.

Conversely, analysts should explore whether excellent levels of service and no delays could be resulting in higher operating speeds and consequently higher severity crashes.

Operational efficiency also applies to pedestrians. For example, long delays between “Walk” phases will cause pedestrians to become impatient and take risks. “Do Not Walk” phases that are accompanied by very low traffic volumes are likely to be ignored. And long crossing distances with inadequate crossing time may result in elderly pedestrians and people with disabilities being stranded in the intersection.

C. Operation of Traffic Control Devices
The performance of the traffic control devices at the study site should be reviewed. In addition to measuring the delays and queues that are resulting from the available traffic control (as described above), this analysis includes:

- Ensuring that traffic control devices (signs, pavement markings, and signal heads) are visible and conspicuous under various light conditions.
- Ensuring that the required traffic control devices are provided where they need to be provided, and identifying existing devices that are not required or that are improperly located.
- Ensuring that the principles of positive guidance (early and repeated direction or warning) are used to guide drivers through complex or non-typical situations.

D. Additional Operational Analysis
Depending on the site characteristics and the review of the crash history and the traffic conflict characteristics, additional operational analysis may be required. The need for this analysis should be determined by the analyst further to a review of the available data and the analysis results. The additional operational analysis could include:

- Speed surveys, and an assessment of the 85th percentile speeds and the pace (the speed interval with the highest proportion of drivers).
- Gap availability and acceptance surveys, and analysis to determine local driver behaviour and tolerance for waiting and risk.
- Pedestrian behaviour surveys and analysis, including crossing behaviour (for example, crossing outside a designated crosswalk or during a "Do Not Walk" phase) and crossing speed.

Information on typical traffic engineering studies can be found in the ITE Manual of Transportation Engineering Studies (1994).

At the end of the operational analysis phase of the work, the analyst should have a strong understanding of the site user profile and operational characteristics. As well, the analyst should have a thorough assessment of the site's operational efficiency and how this efficiency may affect safety performance.

2. Intersection Geometry and Physical Characteristics

A. Compliance
Further to collecting the geometric information for the study site, the analyst should also collect the applicable geometric design standards or guidelines for that jurisdiction, to be used for comparison. A Policy on Geometric Design of Highways and Streets (AASHTO, 2001) is the main reference to be used during the geometric analysis.

The geometric characteristics that should be analyzed include:

- Horizontal and vertical alignments of the approach roads;
- The cross-sectional elements and dimensions of the approach roads;
- Sight distance: in addition to sight distance limitations that may be caused by changes in the vertical and horizontal alignments, sight distance

should also be checked for all intersection movements. Depending on the site context, stopping sight distance, and decision sight distance may need to be checked.

- Acceleration, deceleration, and auxiliary turning lanes. The length and taper dimensions of these lanes should be reviewed.
- Transit facilities. The geometry of bus stops and transit pick-up / drop off points may need to be reviewed, including connectivity between the transit facility and the rest of the pedestrian network.
- Driveway locations and density. The separation between consecutive driveways and between driveways and intersections should be reviewed.
- Roadway lighting, glare, and visual clutter. The available lighting during dark conditions should be reviewed, particularly if the crash data indicates a relatively high night-time crash frequency. The impact of commercial signs and lights (visual clutter) on the visibility of the traffic control devices should also be reviewed. The potential for glare, whether caused by the sun or opposing headlights, should be explored.
- Pavement condition. A paved surface that is worn, cracked, rutted, or showing other signs of distress will likely reduce the available friction with vehicle tires, causing longer braking distances and a higher risk of crashes. In some cases, skid tests can be conducted to determine or confirm the coefficient of friction provided by the pavement under dry and wet conditions.
- Drainage features. Rain water should effectively drain away from the surfaces used by vehicles, bicycles, and pedestrians. A review of a sites' drainage performance may be needed if the crash data indicates that a relatively high frequency of crashes is occurring on "wet" surface conditions.

However, adherence to design guidelines is not the only measure of safety. There are reference documents dedicated to discussing geometric design features from a safety performance perspective, including FHWA 2000 and TAC 1997. Therefore, this task should make use of experienced safety engineering knowledge and judgment, and the application of engineering and road safety principles to the specific site context.

B. Design Consistency

A consistent road is one that provides what drivers are expecting and ensures smooth speed transitions from one section to the next. Inconsistent roadway features can contribute to an increased crash risk. Drivers tend to build up expectancies based on information provided by the road environment. Geometric features that violate these expectancies could cause a crash risk.

A discussion on design consistency is provided in *Alternative Design Consistency Rating Methods for Two-Lane Rural Highways, Final Report* (FHWA 2000).

In general, good design consistency promotes a relatively stable operating speed, and a relatively stable differential between the operating speed and the posted speed limit.

An experienced analyst should look for design inconsistencies that could be

contributing to the crash risk. The inconsistencies can come from either longitudinal differences, inconsistencies in the alignment and the cross-section of the road, etc.

Alignment inconsistencies are experienced by the road user while traveling along a particular road. A simple example would be an intersection approach that provides 12 foot travel lanes that narrow to 10 foot lanes through the intersection. The inconsistent lane width may encourage high speeds on the intersection approach that are incompatible with those required at the intersection.

3. Crash Data

The analysis of crash data is the core of the ISR. Preferably three to five years of historical crash data should be analyzed.

The analyst should examine and "clean" the crash data before proceeding. Typical issues that require attention are:

- Miscoding to the wrong intersection;
- Crashes on private property that have been geographically coded to the subject intersection; and
- Duplicate entries for the same crash.

The average annual crash frequency and rate are the first two calculations conducted by the analyst. This information provides an order of magnitude understanding of the crash experience at the study site.

A. Crash Diagram

A crash diagram should be prepared if possible. The diagram displays the patterns of the crashes as they relate to the site, and assists the analyst in identifying crash risks. As a minimum the crash diagram should include:

- The date and time of the crash;
- The severity of the crash;
- The lighting conditions;
- The road conditions; and
- The weather.

It may be prudent to include additional information on the crash diagram. Site-specific conditions will dictate the need for diagram augmentation.

B. Crash Distribution Patterns

A spreadsheet or database is usually used to analyze and cross-tabulate the crash data and demonstrate distribution patterns. The proportion of all crashes is calculated for various fields. In this way, an unusually high proportion of one crash type can be identified. The crash distribution patterns that are typically analyzed are:

- Temporal Crash Distributions
  - Annual, monthly, daily, and hourly crash patterns are examined to determine if crashes are associated with certain seasonal environmental conditions, or recurrent operating conditions.

- Type and Cause Distributions
  - Impact/configuration, contributing factors (police citation), and severity.
- Environmental Distributions
  - Weather conditions, road surface conditions, and light conditions.

C. Further Crash Analysis

The distributions described above will identify the key crash patterns on which the analyst should focus. The crash distribution analysis may be further enhanced as follows:

- Statistical Significance Testing: Statistical significance testing can be conducted on any of the patterns to determine whether a particular value is statistically over-represented or simply high due to normal fluctuation. Values that prove to be statistically over-represented warrant more detailed analysis. The significance testing can be conducted in comparison to available local, regional, or national data.

  However, significance testing is most useful when comparing the study site characteristics to other nearby sites (local data trends). The procedures and equations for statistical tests of significance can be found in statistics textbooks.

- Cross-Tabulation: Values that are high or statistically over-represented can be cross-tabulated to gain a more detailed understanding of the crash risk. For example, if the crash type distribution demonstrates that rear-end crashes are the most common type, and the road surface condition demonstrates that crashes on "wet" pavement were overrepresented, the distribution of rear-end crashes by road surface condition should be analyzed. This may demonstrate a strong correlation between rear-end crashes and wet pavement conditions.

At the end of the crash analysis phase of the study, the analyst should have a good understanding of what types of crashes are occurring, where they are occurring, and under what conditions the crashes are occurring.

In some instances a site may be selected for analysis even though the crash occurrence is very low. There are many reasons for this situation to surface; although this typically occurs when a well-publicized fatal crash at an intersection prompts an investigation by the MOA.

The course of action in this instance is to proceed with the analysis and report that crash occurrence is low (likely "ordinary"). The potential to eliminate the residual safety concerns rests with the attempt to identify crash risks through other means such as:

- Interviews with police officers, MOA staff, local residents, and business owners to collect anecdotal crash information.
- Conducting traffic conflict studies (if appropriate).
- Interviewing major automobile insurance companies, and trying to obtain insurance claims data.

- Undertaking PGRs, design consistency, conformance checks, and other proactive safety analyses.

4. History of Study Location

The preceding data may be supplemented by municipal records and files containing information on the subject intersection. In some instances, records of changes such as by-laws and construction are important in interpreting the crash data. Other information like public complaints may be anecdotal, yet still serve to provide a more complete picture of the intersections safety performance. Examples of collected information include:

- Previous complaints/allegations on file;
- By-law and maintenance records;
- History of previous transportation/safety investigations at the study location; and
- City/Community Council reports, etc.

5. Possible Road User Navigation Information

Motorists, particularly those who are unfamiliar to the intersection under study gain information on route choice and destinations from available maps. At times the information and detail provided on the printed maps can be unrepresentative of actual site conditions, and may create false expectancies on the part of the motorist.

For instance, two very closely spaced intersections may appear on a map as one intersection because of the scale. It is important for the analyst to understand how drivers might be setting their navigational expectancies and to consider these sources of information.

Field Investigation

A site visit is an essential element of the ISR process. Although a site visit could be used to collect data the main purpose of the site visit is to gain a first-hand appreciation of the physical and operational conditions of the intersection.

The site visit is an opportunity for the analysts to have a detailed look at the high crash risk location. A condition diagram should always be prepared.

The Office Review is usually completed in advance of the field investigation, although this is not necessarily the case. Some analysts prefer to review the crash data prior to the site visit in order to focus the visit on key issues. Other analysts prefer to go to visit the site without any pre-conceptions about safety issues and risks. The order of conduct is a matter of personal preference, and both approaches are acceptable.

The analyst should view the site under various light and traffic conditions,.

The site visit can be used to look for signs that crashes or near misses have occurred at the study site. This might be indicated by skid marks, crash debris, signs of recent repairs, or damage to roadside items such as utility poles.

A field observation report can be helpful to note geometric and operational characteristics and to keep a record of the site visit. The basis of any site visit is careful observation. Sketches,

photographs and video can also be used to capture key observations.

Intersection characteristics to be observed might include:

- worn pavement markings;
- misleading, hard-to-read, misplaced, worn or missing signs;
- pavement markings or signs with poor visibility (in particular at night);
- sight line obstructions;
- unusual road geometry;
- poor lighting at night;
- glare and other environmental conditions;
- congestion or queuing that could frustrate drivers or lead to erratic behaviour;
- land use that generates a high proportion of unfamiliar road users;
- inadequate facilities for vulnerable road users; and,
- distractions.

Analysts visiting a site should take appropriate safety measures to ensure their personal safety, and should avoid creating additional hazards by their presence at the site.

Field investigations should be undertaken to:

- Observe driver/road user behaviour during the following conditions:
  - Peak and off-peak periods;
  - Evening/night;
  - Wet weather and snowy conditions; and
  - Weekend and special events (as necessary).
- Undertake a Positive Guidance Review (PGR) from the perspective of the typical road users;
- Undertake a conformance check of the physical elements of the roadway. These "checks" include an assessment of signs and traffic control, markings, delineation, geometry and street furniture to ensure standard application and consistency from the perspectives of various road users;
- Undertake traffic conflict studies, as necessary; and
- Review the potential causes of crashes at the study location, as required.

Field studies should not be limited solely to traffic control devices or formal elements of the roadway, but should encompass all factors that could impact/improve overall roadway safety.

In addition, they should not solely be focussed on the apparent crash allegations at the study location. The site visit should be used as an opportunity to observe road characteristics that may increase the crash risk, regardless of whether there is related crash data. These potential risks should be documented in the study report, and addressed in a cost-effective manner by the MOA as the opportunities arise. Examples of miscellaneous potential safety risks that could be identified include:

- Discontinuous pedestrian sidewalks or pathways;
- Missing sidewalk ramps for wheelchairs;
- Sidewalk obstructions that block the path of pedestrians on wheelchairs and cause sight-line obstructions;
- Malfunctioning pedestrian call-buttons;

- Roadside hazards
- Placement of utility poles
- Faded pavement markings (lane lines, crosswalks); and
- Malfunctioning street lights.

To ensure that all physical, operational and safety aspects are considered during the field review, a "prompt list" has been provided in **Appendix B**. The prompt list provided should not be used as a substitute for experience, nor considered exhaustive.

The product of the field review should be a series of detailed notes regarding:

- Roadway features and driver/road user behaviour;
- Potential hazards identified by the PGR and conformance check and potential remedial measures to be carried forward to the follow-up plan; and
- Areas that have potential for safety improvement to be carried forward to the diagnosis stage.

Human Factors Review

The goal of the human factors review is to use knowledge of road user abilities and limitations to review the characteristics of the road and the traffic control devices, with the aim of minimizing the potential for errors and crashes. A human factors review evaluates the road environment of the study site by taking into consideration the drivers' need to:

- search a rapidly changing roadway environment;
- process the information from the road environment including road geometry, other traffic, pedestrians, and traffic control devices to make an accurate and timely selection of appropriate lane position, speed, headway and direction; and,
- carry out required maneuvers (curve negotiation, lane changes, or emergency and non-emergency stops).

The study of human factors is highly dependent on understanding the driving task and how road users obtain and process information.

The human factors review is conducted on-site, and could involve driving, walking, and cycling through the site in various traffic, weather, and light conditions. The human factors review should be conducted by an experienced analyst who is familiar with the principles of human factors.

The principal focus of the human factors assessment is on measuring driver performance and assessing the impact of the road environment and driver characteristics (age, inexperience, impairment, unfamiliarity, fatigue, etc.) on expected performance.

A. Consistency and Expectancy
Although drivers have a limited capacity to obtain and process information, they generally cope well. They do so by looking for familiar patterns (e.g. ground mounted signs on the right, freeway exits on the right).

This approach is necessary because when driving even at reasonable speeds, drivers simply do not have time to do anything other than look for information in familiar places and respond in familiar ways.

For example, the 50 percent higher rate of crashes at left exits compared to right exits from freeways, and the doubling of detection distance for unexpected compared to expected objects on the road at night, illustrate the importance of driver expectations. When the road environment corresponds to driver expectations, performance is faster and more accurate.

When road consistency is violated, or when a driver's expectancy is not met, the crash risk is likely to increase.

B. General Procedure

An analysis of the road user task requires considering all the potential movements that a road user might make through a site. For a driver this will include left, straight through and right turn movements at intersections and driveways, and other movements such as merging and overtaking. For a pedestrian this will include walking along the road edge, crossing, especially from bus stops or other drop-off points, to destinations such as shops, and schools.

Information is provided to the road user by the road design itself (wide lanes and paved shoulders mean high speeds), and through road marking, delineation and signing. A drive-through and a walk-through must be conducted to identify any difficulties that the road user might encounter in carrying out all the potential tasks, given the information available. The investigators should keep in mind the crash types which have already occurred, as well as potential performance issues. The goal of the drive-through/walk-through is to:

- experience the site from the perspective of the roadway user, keeping in mind unfamiliar users, truck drivers, inexperienced drivers, older drivers, child and elderly pedestrians, bicyclists;
- observe potential conflicts with other roadway users (as a driver observe pedestrians and bicyclists, as a pedestrian observe drivers); and,
- identify roadway elements and roadside features that may be contributing to driver error.

The on-site human factors review can include a video recording that could be used later to confirm field observations and notes. A video record should include such things as: time and date stamp, 15 to 20 seconds of each approach to an intersection, as well as a slow pan to the right and left at stop lines (including oncoming traffic if possible).

The video should be taken by a passenger who can provide their undivided attention to the recording task. The view should be as close to the view of the driver as possible. Verbal commentary can accompany the recording, particularly to describe signs and pavement markings, which are not as visible on the video as they are to the human eye. Photographs of important features can also be taken for future reference.

C. Positive Guidance

When a potentially unexpected change in the road environment is introduced, or when the driver is required to perform a potentially unexpected task, positive guidance is needed to warn road users of the need to change. Positive guidance requires that messages be conveyed early enough and repeated sufficiently to ensure a smooth transition to the new condition.

Where drivers are required to change speed or path they will perform better if they have adequate warning of these requirements. Good performance with respect to the guidance task requires provision of decision sight distance to choice points, to lane drops and to road bifurcations. Unexpected lane drops require more advance and more emphatic warning. Where a through lane becomes a dedicated turning lane at an intersection, drivers need to be warned in time to allow a lane change.

In order to maintain separation from other vehicles, drivers must be able to predict what the other vehicles are likely to do, and in particular must be ready to respond to vehicles slowing or stopping ahead. Entrances close to intersections are problematic because drivers may be expecting turns to be made at the intersection, rather than immediately upstream or immediately downstream, and rear end crashes may result.

On high speed roads, inconspicuous intersection approaches without a left-turn bay can also lead to such problems, both because a slowing vehicle in the through lane is unexpected, and because drivers have difficulty realizing how rapidly they are closing on other vehicles.

Maintaining separation from other vehicles is particularly critical when drivers merge or cross paths at intersections. A driver limitation, which can lead to crashes involving left turns, is the difficulty of estimating the speed of oncoming traffic. Drivers are reasonably good at estimating the length of a gap but poor at estimating how quickly the gap is closing. Unprotected turns at high-speed intersections can be problematic for this reason.

Another driver limitation is related to habits. Drivers who travel the same road on a regular basis fall into specific habits, and they are less prepared to deal with unexpected events. For example, an unexpected train at an at-grade rail crossing that is otherwise rarely used can pose a significant risk for regular drivers who do not expect the need to stop at this location.

There are many other issues related to human factors that the experienced analyst may encounter on-site. At the end of a properly conducted human factors review, the analyst should have an excellent understanding of how road users are interacting with the physical and operational characteristics of the site, and any potential issues which are over-taxing the road user's ability to make safe and well-considered decisions.

Traffic Conflict Studies

The analysis of traffic conflict data consists of preparing the conflict diagram, and evaluating conflict frequency, rate, severity, type, and temporal distribution. Procedures to conduct this analysis are included in Hamilton Associates (1997). The main components of the analysis are discussed below.

Conflict Diagram: the conflict diagram is similar to the crash diagram. It shows the spatial distribution of all the observed conflicts, as well as the conflict types and the direction of travel of entities (such as vehicles and pedestrians) that are involved. The conflict diagram can also

include information on the time of occurrence and the severity of each conflict.

Conflict Frequency Analysis: the frequency of conflict occurrence is calculated per hour for each of the observation periods (morning, mid-day and afternoon).

Conflict Rate Analysis: the rate of conflict occurrence normalizes the hourly frequency according to the traffic volume entering the intersection.

Conflict Severity Distribution: Each conflict has a severity rating ranging from 2 (lowest severity) to 6 (highest severity). The analysis of conflict severity identifies the average severity rating of all conflicts per observation period, and the distribution of conflicts by severity rating. As well, the severity of specific types of conflicts can be determined to identify the conflict types that created the highest risk. Research indicates that traffic conflicts with severity scores of four or more are more significantly correlated to higher crash risks.

Conflict Type Distribution: The analysis of observed conflicts by type identifies the most frequently occurring conflicts (for example rear-end, left-turn opposing) at the study intersection.

Temporal Distribution: The distribution of conflicts by time period (morning, mid-day, afternoon) helps to identify the times of the day when incidents are most likely to occur. Similar to the crash analysis, cross-tabulations should be conducted between conflict data elements of interest. For example, the temporal distribution of the most frequent conflict type should be reviewed. The traffic conflict analysis results should be compared to the operation and crash analysis results. For example, an unprotected left-turn movement performing at a level of service F, with high frequencies of left-turn opposing traffic conflicts may correlate with high frequencies of left-turn crashes.

Traffic conflict patterns are not expected to duplicate traffic crash patterns. Instead, traffic conflict analysis results often serve to:

- Identify the underlying reasons why certain types of crashes are occurring. As an example, the crash diagram may reveal a high frequency of northbound rear-end crashes, while the conflict diagram may reveal a high proportion of northbound through/southbound left-turn conflicts. It may be concluded that the northbound rear-end crashes are caused by drivers braking suddenly to avoid colliding with southbound left-turn vehicles. To prevent the northbound rear-end crashes, the left-turn conflict needs to be resolved.

- Identify safety concerns that may not be apparent from the crash data analysis. The available crash data typically represents the incidents that meet the threshold for police attendance. The traffic conflict data captures all the incidents that occur during the period of observation, including incidents that may result in low severity crashes not attended by the police.

Upon completion of the traffic conflict analysis, the experienced analyst should have a better understanding of the range of

potentially unsafe maneuvers occurring at the intersection, and a better understanding of some of the underlying causes of crashes.

Diagnosis

The diagnosis stage of the ISR procedure is aimed at understanding and identifying causal factors of crashes at the particular location. All information gathered during the office and field reviews should be thoroughly reviewed/analyzed with the objective of identifying whether there exists one or more opportunities to improve the safety at the location.

Detailed crash analysis should be undertaken to determine if any of the crash characteristics at the study location are "abnormal" compared to that expected for similar sites. Statistical comparisons should be made to appropriate MOA regional data or other comparables.

A number of statistical tests are available to determine whether the proportion of a characteristic found at a specific site is the same as that found in a group of similar sites (e.g., the proportion of rear-end crashes, the proportion of night time crashes, the proportion involving cyclists, etc.). The Chi-square test methodology is included in **Appendix C**. The chi-squared test is a measure of the differences between measured and expected frequencies at an intersection. The required crash data at the subject intersection is the measured frequency. The aggregate crash data from a large number of similar intersections provides the expected frequency. If the subject intersection displays a measured frequency that is greater than the expected frequency, then use of the chi-squared test and reference to standard statistical tables will permit the analyst to determine if the difference is likely a random variation, or likely a real difference. Real differences, also called statistically significant differences, are an indication that the subject location has a site-specific deficiency that may be causing this trend.

The standard police crash report includes a number of crash descriptors ranging from the crash location to the apparent vehicle damage. Many of these characteristics could assist in determining casual factors; however, an exhaustive diagnosis of every crash descriptor may not be warranted to establish probable causes. As a primary review, it is suggested that the following characteristics be analyzed for significant trends.

- Crash distribution by year, month, day of week and time of day;
- Crash severity;
- Crash type; and
- Climate, light and pavement conditions.

Further analysis of such characteristics as vehicle type, driver/pedestrian condition, apparent driver action, etc., may be required to provide further symptoms of the crash occurrences.

Using the above-noted methodologies, this part of the ISR should attempt to correlate crash patterns with contributing circumstances and factors. The link between causal factors and the dominant crash patterns should be based on the collected information, but must also follow a plausible logic. For instance, the setting sun is not a logical contributing factor to a rear-end crash pattern on the northbound approach to an intersection

(the sun sets in the west and is unlikely to cause glare for a northbound vehicle).

Possible causes that are identified for more than one crash pattern should be given priority as it is a strong indication that this factor is likely the cause of crashes.

While driver error is invariably cited as the most common cause of crashes, the likelihood of an error occurring can be greatly influenced by the design, operation, and maintenance of the intersection. These latter factors are typical MOA responsibilities and should be the focus of causation analysis.

Problem Statement

At the end of the diagnosis phase of the ISR, the analyst should prepare a clear and concise problem statement for the study site. The statement should clearly focus on issues and concerns that are increasing the crash risk at the study site.

Each statement describing an issue or concern is typically derived from one or more of the analytical tasks: site visit, crash analysis, operational analysis, geometric analysis, conflicts analysis, and human factors. The statements summarizing the issues or concerns should not be repetitions of the obvious crash patterns. The crash patterns are an outcome; the problem statement should identify the dominant crash patterns but should also identify the cause(s). Such a statement represents the conclusions of the analysis, and suggests to the analyst possible countermeasures. For example, "vehicles slowing down to enter a driveway located immediately downstream of the intersection are unexpected by straight through motorists, and are causing rear-end crashes".

Selection of Countermeasures

Once the safety issues at the study site have been clearly identified, the analyst needs to identify the most suitable countermeasures that can address the identified crash risks. The analyst conducting the ISR is responsible for researching and identifying the specific countermeasures that are most suitable for the subject site. Experience and a good library of current research in the field of road safety engineering will assist in countermeasure identification and selection.

Countermeasure selection should be directed at developing treatments that address the specific areas for safety improvement identified through the preceding stages of the ISR. As such, the primary objectives of countermeasure development and selection are to:

- Determine the range of countermeasures likely to influence the identified safety issues.
- Select countermeasures which can be expected to reduce the frequency or severity of crashes caused by the identified issue. This requires a combination of research, knowledge, experience, and judgment.
- Consider the other safety and operational consequences of the selected countermeasures, for example the potential for increasing the risk of another crash type, the potential for causing delays and congestion, or the

risk of increasing traffic and crashes on an alternate route.

- Consider the feasibility of the countermeasure from both a technical and community perspective. The countermeasure should be suitable for the site context and should fit within the framework of initiatives that are acceptable by the MOA. The countermeasure should also be acceptable to the community and to the affected stakeholders.

- Conduct an economic evaluation to quantify the costs and benefits of implementing the selected countermeasures.

Each selected countermeasure should be matched with one or more specific issue that was identified in the analysis of crashes, geometry, operations, conflicts, and human factors.

Determining the effectiveness of each countermeasure is complicated, requires a sound knowledge-base, and depends on the site conditions. The literature provides guidance regarding the effectiveness that has been achieved by individual countermeasures according to various before and after evaluations.

Potential countermeasures and crash reduction factors for various countermeasures are included in Appendix D. The countermeasures and reduction factors provided in APPENDIX D are presented for general guidance only. They are generally derived from field experience and before-and-after evaluation studies reported in the literature.

When implementing more than one countermeasure, the effectiveness of the combined treatment is not simply the sum of the two crash reduction factors. The effectiveness of a package of countermeasures is calculated as follows:

$$CRF = 1 - (1-CRF_1)(1-CRF_2)\ldots(1-CRF_n)$$

The analyst conducting the ISR has a responsibility to review the site-specific characteristics, identified issues, and crash patterns, as well as the latest research, to determine the most likely changes in crash frequency and severity that may be attributed to the a specific countermeasure.

The product of this component of the ISR is a list of recommended countermeasures and their anticipated benefits/impacts.

Economic Evaluation

In order to make the best uses of limited financial resources, it is expected that those countermeasures that have been identified as viable and effective will be subjected to an economic evaluation. It is common practice in road safety engineering for the economic analysis to take the form of a benefit/cost (B/C) analysis.

The B/C ratio is the monetary crash savings divided by the countermeasure cost. Typically countermeasures that have a B/C ratio of greater than 1.0 are considered economically sound. However, the analyst must remember that the benefit/cost calculation is an economic tool and does not determine or predict the level of "safety" of any intersection. It is a

technique that is used to help road authorities make decisions about infrastructure investments and the allocation of limited funds. The parameters used in the benefit/cost calculation are generally accepted by the traffic engineering profession but should be treated as variable as they are determined by social values, economic inflation, acceptable rates of return and alike.

Ultimately the decision to invest in increasing the level of safety at a particular location rests with the road authority and should consider the benefit/cost ratio as only one of many elements in the decision-making process.

The B/C ratio is determined by:

- Using the crash record of the site and the estimated effectiveness of the countermeasure to determine the number of crashes saved within each severity;
- Determining the societal savings derived from the countermeasure by using appropriate "cost of crash" figures;
- Estimating the implementation and (if appropriate) maintenance costs associated with the countermeasure;
- Estimating the service life of the countermeasure, and the salvage value (if any);
- Select an interest rate that is appropriate for the time period under consideration; and
- Calculate the B/C ratio using the appropriate equation (FHWA, 1997).

The B/C analysis can be used to assist in countermeasure selection by employing one of the three following procedures:

- Net Benefit Method: For countermeasures with a B/C ratio of greater than 1.0 rank measures with the highest benefit minus cost total.
- B/C Ratio Method: For countermeasures with a B/C ratio of greater than 1.0 rank those measures with the highest B/C ratio.
- Incremental B/C Method: For countermeasures with a B/C ratio of greater than 1.0, rank them in order of increasing cost. Calculate the incremental B/C ratio for each successively costly option. Measures with incremental B/C ratio greater than 1.0 are implemented.

In all three of the above methods, the intent is to implement the highest ranking countermeasures and to continue down the list until funds are depleted. Of course, if a countermeasure would address the same problem as a higher ranked countermeasure then it may be skipped.

The Alaska DOT already has an evaluation procedure in place for their HSIP. It is recommended that the MOA adopt the same procedure and share information with the DOT.

The grouping of the countermeasures into workable strategies is the final step of the analysis. The most common method of grouping the countermeasures into improvement strategies is based on the urgency of implementation:

- *Immediate Actions* should include countermeasures that should be implemented soon after the road agency is made aware of the issues. Examples include trimming over-hanging branches that are obscuring a signal-head, and replacing a STOP sign that has lost its reflective sheeting.

- *Short-Term Actions* include relatively inexpensive countermeasures that could be implemented in the short-term, and that could be funded from operational or maintenance budgets. Examples include re-marking faded pavement markings; and re-timing signals.

- *Medium-Term Actions* include relatively more expensive countermeasures that may require design work and possibly the acquisition of right-of-way. Examples include the provision of a left-turn lane, removing major road-side obstacles, and installing a new signal.

- *Long-Term Actions* include relatively expensive countermeasures that may require long-term planning, design, and extensive public consultation. Examples include twinning a road segment, providing grade separation, or re-aligning a road.

The greatest safety value is derived from the relatively quick implementation of countermeasures.

Implementation Plan

The identification and documentation of the physical and operational hazards determined during the ISR must be coupled with a Implementation Plan. The Implementation Plan must identify what measures will be taken, by whom, and when, and it must effectively communicate these decisions to each of the stakeholders identified above.

The objective of a Implementation Plan is to ensure that the:

- Department, jurisdiction and/or agency that is responsible for implementing the proposed countermeasures is properly notified of the action required;

- Urgency or period to implementation of these remedial and countermeasures are properly conveyed; and

- Remedial measure, when completed, is done in accord with best practices, has addressed the hazard and has not created unforeseen negative impacts on traffic operations or safety at the location.

Documentation

The product of the ISR must be a technical report that can be referenced for future projects. The primary objective of the ISR report is to succinctly outline the:

- Study process and scope;
- Available data and methodologies employed; and
- Conclusions and recommendations of the review.

To attain this objective it is suggested that the following be outlined in the report:

- Safety allegations at the study location and their source;
- Data collection activities and availability;
- Field observations, scope and dates;
- Identified potential safety hazards and appropriate remedial measures;
- Analysis methodology;
- Countermeasure evaluation;
- Recommendations; and
- Implementation plan, as required.

An example table of contents for a safety review is included in **Appendix E**.

The following items should be documented and attached to the final document, if and when they become available, to help track the implementation of the study recommendations and their effectiveness.

- Details regarding the acceptance or rejection of recommendations by others;
- Implementation plan activities and completion; and
- Results of the Evaluation program.

Evaluation Program

An evaluation program should be developed to assess the impacts of the selected countermeasure. The scope of the evaluation program will be a function of the nature of the countermeasures and their potential effects on operations and safety at and adjacent to the study location. The objectives of the evaluation program are as follows:

- To focus-in on the dominant crash types to determine if the recommended countermeasure has improved safety at the specific location by causing a decline in the dominant crash types;
- To ensure that the recommended treatment does not cause adverse safety or operational impacts on the road network;
- To improve techniques and practices for identifying existing or potential operational concerns;
- To provide quantitative data for the establishment of crash reduction factors for the MOA; and
- To justify upgrading the MOAs transportation related standards, policies and procedures that are applied in all areas from transportation planning to roadway and right-of-way maintenance.

The Evaluation Program should have a clearly understood monitoring frequency, duration, and objectives, as appropriate for the measure installed. The need to advise stakeholders of the Evaluation Program should be considered, but may not always be necessary. However, should the Evaluation Program result in a modification or removal of the originally proposed countermeasures, further notification to the stakeholders is likely required.

Evaluation studies for road safety projects are most effective when they are well planned in advance. The evaluation task should be considered well before implementation. In particular, the analyst should establish the appropriate evaluation methodology, and identify the associated data requirements.

Evaluations of countermeasures require a minimum of one year of "after" crash data. This requirement allows an annual weather cycle to pass, and reduces the skew caused by non-typical events.

The evaluation process should ensure that a noted change in the number of crashes has been caused by the improvement (countermeasure) and not by other confounding factors or causes. If other factors are allowed to contribute to the noted change, then sound conclusions about the effect of the countermeasure cannot be made.

While researchers have discussed many classes of these confounding factors, three main factors are most relevant to road safety evaluation. These factors include history, maturation and regression artefacts.

History refers to the possibility that factors other than the countermeasure being investigated caused all or part of the observed change in crashes. As a simple example, if the countermeasure being evaluated is pavement grooving to improve skid resistance and reduce rear-end crashes, then a significant reduction in the amount of rainfall in the post-implementation period may explain a change in crashes. Therefore, the evaluation should separate the countermeasure effect from the effect of other factors.

Maturation refers to the effect of crash trends over time. For example, a comparison of crashes before and after the implementation of a specific countermeasure may indicate a reduction attributed to the countermeasure. However, an alternate explanation would be that this reduction is part of a continuing decreasing trend occurring over many years.

Regression artefacts, also known as regression to the mean, refer to the tendency of extreme events to be followed by less extreme values, even if no change has occurred in the underlying mechanism which generates the process. In other words, "the highest will get lower and the lowest will get higher". Road improvement sites are usually selected for treatment because of a recorded high occurrence of crashes. This high occurrence may regress to the mean in the after-treatment period regardless of the treatment effect. This will lead to an overestimation of the treatment effect in terms of reducing crashes. The regression to the mean bias is considered the most important source of error in the evaluation of road safety programs.

For a detailed description on the state-of-the-art in observational before-after studies for traffic safety, the reader is referred to Hauer (1997) for more information.

In summary, modern evaluation studies for road safety improvements should account for the challenges described in: History, Maturation, and Regression Artefacts. The results of evaluation methods that do not account for these issues are considered suspect. The modern accepted method to address these issues involves the use of comparison groups and the Empirical Bayes approach. The summary findings of an evaluation study should include a brief description of the evaluation methodology used, to help determine the significance and quality of the results.

Due diligence and legal liability

Whether an ISR has been undertaken or not, the MOA is potentially liable for crashes on, and the condition of their roads. A crash caused by an undetected safety problem that should have reasonably been detected will likely result in legal action against the MOA. Therefore, it is prudent for the analyst to be thorough and complete in undertaking an ISR. Due diligence suggests that the analyst should be correcting crash problems that are occurring, and identifying elements of the road, and the roadside that can reasonably be expected to cause a crash, or make a crash more severe.

The key principle in the foregoing discussion is that of *reasonableness*. The legal system does not expect the MOA to be *perfect*; the system expects the MOA to be reasonable.

Once a countermeasure is, or countermeasures are, selected it is equally important that the associated implementation plan be reasonable. It is recognized that some countermeasures cannot be implemented immediately, and that some countermeasures may be delayed several years. The time lag between selection of a countermeasure and implementation should be rooted in sound logic and reasoning.

In some instances, the MOA may find itself in the position where it does not select a "more effective" countermeasure, or elects to "do nothing". This situation might arise because some individual recommendations may not be desirable or implementable for other reasons (e.g. impacts on congestion and/or travel patterns, or environmental damage).

Not selecting a more effective countermeasure is permitted, but must be meticulously documented. Typical reasons for refusing a safety recommendation are, that the countermeasure(s):

- Will solve the current safety problem, but is expected to create another safety problem of equal or greater magnitude;
- Will create an intolerable traffic situation;
- Contravene MOA policy (as approved by Council);
- Are technically infeasible;
- Are unaffordable, even in the long-term;
- Will cause significant environmental damage; and
- Will severely impact on the cultural environment

The above list is not exhaustive, and other valid reasons for not selecting a safety countermeasure may exist. Nonetheless, only the first reason in the above list is likely to be quantified and evaluated in an objective manner. The remaining reasons are essentially trading-off safety impacts with other impacts (i.e., environment, traffic congestion). There is a degree of subjectivity included in making the trade-off, and hence the decision to select a countermeasure.

Once again, each situation is unique. It is not possible to provide a definitive guideline on when a countermeasure can be rejected for other reasons. However, it is clear that the logic should be considered reasonable and should be documented.

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4 Closing Notes

The surface transportation system is made up of vehicles, road users, and the road itself; all of which interact in a complex manner. While the procedure presented in this document is relatively simple and straightforward to undertake, it does not guarantee that the appropriate amount of safety has been inculcated into each location reviewed. Besides being aware of corporate (municipal) policies respecting safety and environmental impacts, the analyst must have a sound understanding of the link between safety and planning, design, operation and maintenance decisions.

In short, this procedure must be applied by a qualified road safety analyst.

APPENDIX A

THE POSITIVE GUIDANCE APPROACH – A SHORT PRIMER

Overview:

A Positive Guidance Review is a process that uses an in-depth knowledge of human factors and the driving task to screen roadways for information deficiencies, expectancy violations, workload issues, environmental factors and operational scenarios that may potentially contribute to the occurrence of driver error and crashes.

It is a holistic approach that treats the roadway, the vehicle and the driver as a single, integrated system. It recognizes drivers as the information gatherers/decision makers within the system, and focuses attention on assuring that they get the information they need, when they need it, in a form they can understand, in time to make rapid, error-free decisions and to take appropriate actions. When this occurs the system functions most effectively and the driving task is successfully accomplished. Creating and sustaining a supportive information environment on the roadway is the goal of Positive Guidance.

In conducting a Positive Guidance Review, the analyst attempts to view the roadway through the eyes of an "average" driver – postulating as to what their perceptions, interpretations, expectations and actions might be. This is done in order to formulate theories and possible explanations regarding the cause or causes of prior or potential conflicts and/or crash occurrences.

Positive Guidance can be applied as a pro-active measure, to identify potentially hazardous locations without a demonstrated crash history, or as a supplementary investigative tool where crashes are occurring and conventional analysis offers no ready explanation for their occurrence. In such circumstances, a Positive Guidance review may stimulate new lines of conventional enquiry, or put forth a plausible scenario outlining the likely causality of a particular type of occurrence. This, in turn, may permit new, potentially mitigating measures, to be identified and applied.

It is this linking of the crash record - or of the potential for crashes - to specific aspects of the roadway environment, via a plausible chain of causality, that is the key strength of Positive Guidance. This exercise allows previously unrecognized hazards to be identified, assessed as to their contribution to the occurrence of crashes, and addressed. Once a likely crash scenario has been established, mitigating measures capable of breaking the chain of causality often become evident. Where further evidence is needed to confirm suspected causal factors, new lines of investigation can often be pursued to verify them.

Positive Guidance normally focuses on low-cost, information-oriented improvements that can be implemented quickly, either as solutions in and of themselves, or as interim improvements until a more definitive solution can be achieved. It may also identify the need for additional investigation, in the form of conventional engineering analysis, to support theories regarding the contributory causes of crashes, and to justify mitigating measures.

Human Factors and Positive Guidance:

Although it was first formalized as a technique in the 1970's, Positive Guidance remains a credible and highly effective approach to solving operational problems not conducive to more conventional engineering analysis and resolution. The strength of the technique lies in its holistic, systems approach to the complex interactions that occur between the driver, the vehicle and the road, and in its use of human factors in understanding and aiding the driver in task performance. It is often credited with finding low-cost, highly effective solutions for operational problems that otherwise defy solution.

Most crashes are attributable to driver error. Drivers make errors for many reasons, including inattention and impairment. However, many errors occur for reasons beyond the direct control of the driver. Errors in judgement on the part of the driver may stem from a lack of information, a lack of clarity in the information available, or insufficient time in which to respond appropriately. Drivers may also be surprised, and fail to respond appropriately, or at all, when confronted by unexpected conditions or events. Regardless of their cause, driver errors are viewed as system failures.

Driver errors may have little or no negative outcome, amounting to nothing more than a momentary traffic delay or a missed turn. These are considered to be low severity system failures. Occurrences where a driver's error substantially heightens risk (erratic maneuver, traffic conflict) or results in an actual crash, are treated as moderate and high severity system failures respectively.

In circumstances where the driver received deficient information, or was taken by surprise by a roadway feature, the roadway itself must share some responsibility for the occurrence. Viewed in this manner, system failures in which the roadway played some role represent opportunities to better understand and improve the roadway information system, thus preventing similar errors and occurrences in the future.

Drivers, as humans, have a diverse range of physical and cognitive capabilities and limitations that define how fast, how accurately or how poorly they perform various tasks. These human capabilities and limitations are quantified through the study of ergonomics, or human factors. In driving, processes such as information gathering, decision-making and action-taking are of particular interest and importance.

The Positive Guidance approach uses human factors knowledge to predict the outcomes of interactions between drivers and roadways, identifying opportunities for driver error that may result in crashes. It approaches the problem in two ways. First, it examines the roadway from the perspective of an unfamiliar driver, identifying the information needs, workload challenges and expectations created. Then, it examines the available information, and looks for gaps or inconsistencies or between what is needed, what is expected, and what is encountered. If at any point the roadway fails to fully meet the information needs of the driver, or if a feature of the roadway is in some way contrary to the driver's reasonable expectations and surprise results, then the potential for driver error exists.

Drivers continually collect information, most of it visually. They look at both formal information sources (i.e.: highway signs) and informal ones (i.e.: pavement joints, tree lines and parallel features), drawing conclusions from each. They make scores of decisions every second. They cope by juggling tasks, sampling the available information to find what they need, and making decisions based on what is most pressing.

Drivers also have short and long-term memory that allows them to build up a store of experiences. Drivers bring the benefit of their experience to every situation, filling in the missing pieces and anticipating what will happen next based on recent observations, and past occurrences. This is known as expectation.

Driving tasks can be grouped into three levels, by order of importance, as follows:

- Control;
- Guidance; and
- Navigation.

Each level forms a foundation for more complex tasks to be built upon it. At the base is control, which involves managing the vehicle. Guidance primarily involves speed and path decision-making – staying on the road, responding to traffic controls, and avoiding conflicts with other vehicles. Navigation involves making choices at decision points and getting to a destination across a roadway network. The driver must be in control of the vehicle before guidance-level decisions can be exercised. Similarly, implementing navigation decisions requires both vehicle control and vehicle guidance (speed and path) to be well in hand.

When all the information a driver needs to make decisions and take actions is available, in a simple, legible and explicit format, with sufficient time to make decisions and take actions, performance is usually rapid and error free. When information is missing, misplaced, obscured, conflicting or confusing, things get more difficult. As driving tasks multiply, or become more complex, this further adds to the driver's workload. Too much information or too many tasks can overload the driver, resulting in missed information, delayed or flawed decisions, errors, and ultimately, crashes.

Often, when the available information is insufficient to support a clear decision, drivers will rely on their expectations. This is fine as long as everything turns out as they expect. When those expectations are violated however, the driver is surprised, and must collect new information, rethink what to do, and then take action. If the time available is insufficient, or if other tasks go undone as this process takes place, errors can again occur, leading to crashes.

Under Positive Guidance, crash records are examined to determine what role information deficiencies and violations of driver expectations may have played in a crash. Clues regarding roadway features uncovered through an examination of crash records, along with circumstances liable to result in system failures but perhaps not yet responsible for crashes, are examined during the field review.

Applied on a section of roadway, the Positive Guidance review process maps information needs, identifies sources of information, tracks driver expectations and monitors workload. It seeks information deficiencies, expectancy violations, periods of excessive workload and distractions. It examines not only the formal sources of information, but the informal sources as well. It strives to assure that drivers receive all the information they need, when they need it, in a form they can readily use, with sufficient time to make decisions and take actions. It seeks to avoid peaks and valleys in workload demands, and to minimize distractions. Where driver expectations cannot be met, it ensures that they are thoroughly restructured by conspicuous information presentations, avoiding surprises and assuring that the driver's expectations are consistent with reality at all times.

In practical terms, the recommendations from a Positive Guidance review seek to refine the information stream available to the driver. This may involve employing one or more of the following techniques:

- Introducing new sources of information to fill gaps or restructure expectations;
- Clarifying, simplifying or emphasizing existing sources through coding, repetition or redundancy;
- Clarifying or eliminating conflicting information; or
- Identifying competing or distracting information not immediately relevant to the tasks at hand, and either eliminating it or spacing it out linearly along the road to balance the information stream and prevent localized overloads.

APPENDIX B

INTERSECTION SAFETY REVIEW PROMPT LIST

General

1. Scope:
Review all pertinent documentation to gain an understanding of the function of the intersection; including mobility/access function of intersecting streets, user characteristics, design vehicles, access, adjacent development, existing network information, and future network expansion.

2. Intersection Control Warrants
Is the existing traffic control appropriate for the intersection? Is congestion or collision risk such that a different form of intersection control is warranted?

3. Landscaping
Landscaping along the approaches in accordance with guidelines? Required clearances and sight distances restricted due to future plant growth?

4. Glare
Severity of head light glare during night time operations. Do areas exist where sunlight reduces visibility?

5. Traffic Calming
Are traffic calming measures effective at reducing vehicle speeds? Is traffic calming required?

6. Congestion Areas
Have areas of congestion been identified? Are areas of regular congestion visible by approaching road users?

7. Street Network
Have changes in traffic flow altered hierarchy of streets.

8. School and Recreation Areas
Is posted speed limit appropriate for neighbourhood activities? Is speed limit effective at controlling traffic speed? Is existing signage sufficient at notifying motorists of upcoming activities, or is some other traffic control device necessary? Visibility of signage from approaching traffic adequate? Visibility of school and recreational areas by approaching traffic. Does on-street parking exist near school? If so, will visibility of children be obstructed by parked vehicles? Do crosswalks exist in area? If so, what is their condition? Does approaching traffic adhere to pedestrian rules at crosswalks or are further traffic control measures necessary? (Crossing guard, pedestrian corridors, etc.)

9. Environmental Considerations
Check the effects of adverse weather conditions on the facility.

Approach Alignments and Cross Sections
1. Classification
Is road classification appropriate for current traffic distribution and volume? Are one-way streets clearly marked at the intersection?

2. Design Speed / Posted Speed
Check the appropriateness of the design speed for horizontal alignment, vertical alignment and visibility. Is the traffic following the posted speed?

3. Cross Sectional Elements

3.1 Drainage
Is there possibility of surface flooding or overflow from surrounding or intersecting drains and watercourses? Does the roadway have sufficient drainage? Are the storm grates cyclist friendly?

3.2 Lane Width
Is the lane width adequate for the road classifications and/or traffic volumes?

3.3 Cross Slopes / Superelevation
Do crown and cross slopes provide sufficient storm water drainage and facilitate de-icing treatments? Do different rates of cross slope exist along adjacent traffic lanes?

3.4 Turning Radii
Is sufficient turning radii provided for the design vehicles?

3.5 Curbs and Gutters
Are curbs and gutters installed where necessary? Are curbs and gutters constructed according to guidelines? Physical condition of curbs and gutters are adequate?

3.6 Boulevards and Borders
Are boulevards and borders constructed according to guidelines. Does street furniture in these areas pose safety concerns to road users?

3.7 Sidewalks
Physical condition of sidewalk. Is sidewalk width adequate for pedestrian volumes? Do objects exist on or near sidewalk that cause pedestrians to use street (i.e. canopies, patios,

advertisement signs, etc.)? Is the sidewalk aligned with the crosswalks and the pedestrian signal heads?

4. Alignment

4.1 Horizontal
Are there horizontal curves that cause sliding in adverse weather conditions? Is the signing of horizontal alignment adequate?

4.2 Vertical
Are there excessive grades that could be problematic in adverse weather conditions?

4.3 Combined Vertical and Horizontal
Check the interaction of horizontal and vertical alignments in the road.

5. Sight Distance
Any obstructions that could interfere with sight distance along approaches? Determine if adequate sight distances are provided.

6. Readability by Drivers
Check for sections of roadway having potential for confusion such as alignment problems, old pavement markings not properly removed, streetlight/tree lines don't follow road alignment.

Intersection
1. Type
Is the type of intersection appropriate for current and future traffic volumes as it relates to safety? Can intersection design accommodate all design vehicle classifications?

2. Layout
Is layout of the intersection appropriate for the road function? Are the lane widths adequate for all vehicle classes? Are there any upstream and downstream features which may affect safety? (i.e., "visual clutter", angle parking, high volume driveways) Junctions and access adequate for all vehicle movements?

2.1 Maneuvers
Are vehicle maneuvers obvious to all users? Are there any potential conflicts in movements? Do certain traffic movements need to be prohibited/discouraged by using one-way streets, cul-de-sacs, chokers or medians?

2.2 Channelization
Are channelization features effective? Any areas of uncontrolled pavement that may require

channelization features?

2.3 Auxiliary Lanes
Are they of appropriate length? Is decision sight distance for entering/leaving vehicles adequate? Are tapers installed where needed? Are they correctly aligned? Are auxiliary heads necessary?

2.4. Islands
Presence of visual clutter on island affecting sight distance? Is an island required to channel vehicle traffic at the current location? Are the dimensions of the island adequate for the intersection (width, length, turning radius)? Is the existing island clearly visible to drivers?

3. Sight Distance at Intersections
Are all sight distances adequate for all movements and road users? Are sight lines obstructed by signs, bridge abutments, buildings, or landscaping? Could sight lines be temporarily obstructed by parked vehicles, snow storage, seasonal foliage, etc.?

4. Controls

4.1 Markings
Are pavement markings clearly visible in day and night time conditions? Check retro-reflectivity of markings. Are all necessary pavement markings present?

4.2 Signs
Check visibility and readability of signs to approaching users. Check location and noise induced by signs. Check for any missing/redundant/broken signs. Is adequate warning provided for signals not visible from an appropriate sight distance?

4.3 Signals
Have high intensity signals/target boards/shields been provided where sunset and sunrise may be a problem? Check location and number of signals. Are signals visible? Are primary and secondary signal heads properly positioned?

4.4 Signal Phasing
Are minimal green and clearance phases provided? Is protected left turn phasing required? Is the signal phasing plan consistent with adjacent intersections?

5. Landscaping
Will current or future plant growth interfere with required clearances, traffic flow devices, or sight distances?

Road Surface

1. Skid resistance

Does adequate skid resistance exist along curves, intersection approaches and steep grades? Has skid resistance testing been carried out?

2. Pavement Distress

Check that pavement is free of distresses. (i.e., potholes, rutting, etc.)

3. Surface Texture

Visibility in wet conditions. Can visibility be reduced due to sunlight conditions? Headlight response during night time operations.

4. Ponding

Ensure that pavement is free of depression areas where ponding can occur.

Visual Aids

1. Pavement Markings

Are centre lines clearly visible at all times? Have old pavement markings been removed? Check retro-reflectivity of existing markings. Could obliteration problems cause confusion?

2. Delineation

Is delineation adequate? Effective in all conditions? Are retro-reflective devices intended for heavy vehicle operators at their eye height? Are chevron markers placed correctly? Has retro-reflectivity been measured?

3. Lighting

Will street lights create glare for road users on adjacent roads? Check appropriate location of street lights. Do locations exist where lighting may interfere with traffic signals or signs? Has lighting for signs been provided where necessary?

4. Signs

Are all current signs visible? Do conditions exist which require additional signs? Check correct location of signs. (i.e., proper height, offset, distance in advance of hazard.) Do any signs restrict the sight distances of road users? Check effectiveness of signs in all operating conditions (day, night, rain, fog, snow, etc.) Are any signs redundant/missing/broken? Do any signs contradict one another? Check condition of sign and supporting structure. Are any existing signs no longer applicable? Are proper grades of retro-reflective sheeting used?

Physical Objects

1. Medians

Is type of median chosen appropriate for width available? Are slopes of grass median adequate? Are median barriers sufficiently offset from roadway? Is there sufficient width for overpass/underpass piers and light standards? Check appropriate spacing between median crossovers.

2. Hazardous Object Protection

Is adequate protection provided where required? (i.e., barriers, energy attenuators). Check for guy wires that may interfere with protection. Are end treatments sufficiently anchored? Is pavement buildup reducing the effectiveness of roadside guardrails/barriers? Are dimensions (i.e. length) of protection appropriate? Is there appropriate transition from one barrier to another? Are reflectorized tabs used where necessary?

3. Clear Zone

Ensure no objects (temporary or permanent) are within the required clear zone. Check that clear zone is of adequate dimensions.

4. Culverts

Check adequate protection of culverts at abutting driveways and intersecting roads.

5. Poles and Other Obstructions

Are poles and other obstructions adequately protected? Unprotected median widths appropriate for lighting poles. Check clearance for overhead wires. Have frangible or slip-base poles been used? Appropriate positioning of traffic signal and other service poles.

6. Railroad Crossings

Ensure proper active/passive signing and pavement markings. Check sight distances for signing and also approaching trains. Are gates of adequate width? Are at-grade crossings approximately level with traveled roadway?

7. Manholes

Are manholes too high or too low?

Road Users

1. Motorized Traffic

1.1 Heavy Vehicles/Public Transport

Can facility accommodate movements of heavy/public transport vehicles? (clearances, turning radii, shoulder widths, operational capacity) Is there adequate signage of heavy

vehicle/public transport activity? Check location of bus stops and clearance from the traffic lane. Check visibility of bus stops by approaching traffic. Are bus bays/lanes required?

1.2 Road Maintenance/Emergency Vehicles
Can facility accommodate movements of road maintenance and emergency vehicles (clearances, turning radii, shoulder widths)? Are medians visible and in adequate locations for these vehicles? Are they properly signed?

2. Non-Motorized Traffic

2.1 Cyclists
Is there adequate width along the shoulder for cyclists sharing the street with motorists? Are shoulders properly maintained for cyclist traffic? Are alignment and cross section for bicycle facilities appropriate? If bike route exists, are adequate markings and signage provided? Are bike lanes required?

2.2 Pedestrians
Will snow storage disrupt pedestrian access or visibility? Are hand rails provided (on bridges, ramps)? Check signal timing (cycle length, pedestrian clearance time). Is there adequate signage for pedestrian paths? Are sight lines for pedestrians clear? (i.e., around parked cars) Are pedestrian bridges necessary?

2.2.1 Elderly and Disabled
Are there adequate provisions for the elderly, the disabled, children, wheelchairs and baby carriages (curb and median crossings, ramps, raised crosswalks, curb cuts, etc.)? Does tactile paving exist? Is it properly used?

2.2.2 Paths and Crosswalks
Check location of crosswalks along the road (signage, sight distance, spacing). Check the visibility of traffic from the crosswalk and the visibility of pedestrians from the traffic flow. Verify condition of crosswalk markings.

2.2.3 Barriers and Fencing
Is there adequate fencing to guide pedestrians and cyclists to crossings/overpasses? Check visibility at night. Are solid horizontal rails present in the fence?

Access and Adjacent Development

1. Right-of-way

Check width of ROW as affected by access requirements. Are there any upstream or downstream factors which may affect access? Ensure that traffic signals and lighting on adjacent roads do not affect driver perception of the road. Will there be "visual clutter" (excessive commercial signing or lighting) beyond ROW?

2. Driveways / Approaches

Check interaction between driveway and road. (i.e., sight distance) Check for adequate space between driveways/approaches on same side of street. Ensure that driveways across the road from one another are staggered. Check effects on traffic patterns.

3. Roadside Development

Check effects on vehicle distribution.

4. Building Setbacks

Ensure adequate distance from edge of traveled roadway.

5. Loading/Unloading Areas

Interaction between loading areas and traffic flow. Visibility of loading areas. Check if heavy vehicles block visibility to signs and signals while in loading/unloading areas. Is loading area adequately signed?

Parking

1. Street Parking

Is parking orientation (parallel, angled) along route appropriate? Are parked vehicles obstructing sight distances? Parking restrictions during peak hours. Are excessive manoeuvers required to park a vehicle within the dimensions of the parking space? Are the parking facilities along a route appropriate for the classification of the route? If not, should off street parking be provided? Are parking restrictions near intersections sufficient? Visibility and circulation of pedestrians around parked vehicles.

APPENDIX C

STATISTICAL CRASH ANALYSIS METHODOLOGY

Calculation of Critical Crash Rate

The critical crash rate represents the expected tolerable crash rate of intersections with similar characteristics (in this case, the same traffic control). The critical rate is calculated based on the system wide average crash rates for intersections of similar control type. If the actual crash rate is greater than the critical rate, the deviation is probably not due to chance, but to the unfavourable characteristics of the intersection. The equation for the critical rate of the intersection is expressed as follows:

$$Rc = Ra + k\sqrt{\frac{Ra}{M}} + \frac{1}{2M}$$

Where,

Rc = Intersection critical crash rate
Ra = Average crash rate for signalized intersections
M = Vehicle exposure at the location in million vehicles entering per year
K = Probability constant (a value of 1.65 is used to obtain a 95 percent confidence level)

The Chi-Square Test

The chi-squared test is a measure of the differences between measured and expected frequencies at an intersection. If the subject intersection displays a measured frequency that is greater than the expected frequency, then use of the chi-squared test and reference to standard statistical tables will permit the analyst to determine if the difference is likely a random variation, or likely a real difference. Real differences, also called statistically significant differences, are an indication that the subject location has a site-specific deficiency that may be causing this trend.

The chi-square test can be calculated using the following equation:

$$X^2 = \frac{(x - \overline{p}n)^2}{\overline{p}n} + \frac{[(n - x) - n(1 - \overline{p})]^2}{n(1 - \overline{p})}$$

Where,

X^2 = Chi-square test value
p = The MOA average proportion of crashes that are the crash type being investigated expressed as a decimal
x = The total number of crashes of the type being investigated at this site
n = The total number of crashes at the site

The chi-square test is not reliable when the expected frequency is less than five. The expected frequency is determined by multiplying “p” and “n”. If the product of “p” and “n” is less than five, then the Fisher Exact test should be used.

Chi-square values associated with different levels of confidence are shown in Table C1. If the calculated chi-square value exceeds the value in the table, then the crash type being investigated is likely …at that level of confidence. For instance, if rear-end crashes are being investigated at Intersection XY, and the chi-square value is 6.2 then the rear-end crashes at Site XY are over-represented to a XX% level of confidence.

APPENDIX D

POSSIBLE COUNTERMEASURES AND CRASH REDUCTION FACTORS

Table D1
Possible Causes and Countermeasures for
Head-Left/Rear-Left Crashes

Cause of Crashes	Possible Countermeasures
Inadequate Gaps in Oncoming Traffic	Add two-way STOP/YIELD at intersection
	Change from two-way to all-way STOP
	Signalize intersection
Inadequate Signalization for Left-Turn Volume	Retime traffic signal
	Provide lead/lag or split phasing
	Add pretimed, protected left-turn signals
	Install signal actuation
	Upgrade signal controller
	Upgrade signalization
	Install dual left-turn lanes, signs, and signals
	Prohibit turns
	Reroute left-turn traffic
	Sign one-way street operation
Inadequate Signal Change Interval	Increase yellow change interval
	Add all-red clearance interval
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Restricted Sight Distance	Reduce obstructions in median
	Favorably offset opposing left-turn lanes
	Move intersection away from curves/crests
	Reduce obstructions on insides of curves
	Flatten roadway curves
	Lower roadbed on hill crests

Table D2
Possible Causes and Countermeasures for
Angle Crashes at Signalized Intersections

Cause of Crashes	Possible Countermeasures
Poor Visibility of Traffic Signal	Remove signal sight obstructions
	Post SIGNAL AHEAD warning signs
	Install/replace signal visors
	Add signal back plates
	Add/relocate signal head
	Install 12-inch signal lenses
	Install advance flasher-signs
	Upgrade signalization
Unexpected/ Unnecessary Stops Due to Signal	Retime traffic signal
	Upgrade signal controller
	Provide signal progression
	Install signal actuation
Inadequate Signal Change Interval	Increase yellow change interval
	Add all-red clearance interval
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Slippery Surface	Post SLIPPERY WHEN WET signs
	Improve drainage
	Groove pavement
	Resurface roadway
Proper Stopping Position Unclear	Add stop bars/crosswalks
	Add/improve lighting
Unsafe Right-Turns-on-Red (RTOR)	Reduce RTOR Sight Obstructions
	Add right-turn lane channelization
	Provide right-turn overlap (green arrow)
	Prohibit RTOR
Restricted Sight Distance	Eliminate parking
	Remove obstructions from sight triangle
	Close/relocate driveways near intersection

Table D3
Possible Causes and Countermeasures for
Angle Crashes at Unsignalized Intersections

Cause of Crashes	Possible Countermeasures
Unexpected Cross Traffic	Install intersection warning signs
	Move intersection away from curves/crests
Restricted Sight Distance	Eliminate parking
	Remove obstructions from sight triangle
	Close/relocate driveways near intersection
	Add two-way STOP/YIELD at intersection
	Change from two-way to all-way STOP
	Signalize intersection
Poor Visibility of STOP/YIELD Signs	Remove sign sight obstructions
	Install larger signs
	Construct rumble strips in pavement
	Install STOP/YIELD AHEAD signs
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Slippery Surface	Post SLIPPERY WHEN WET signs
	Improve drainage
	Groove pavement
	Resurface roadway
Proper Stopping Position Unclear	Add stop bars/crosswalks
	Add/improve lighting

Table D4
Possible Causes and Countermeasures for Rear-End/Rear-Right and Sideswipe/Same-Direction Crashes at Signalized Intersections

Cause of Crashes	Possible Countermeasures
Turning Vehicles Slowing or Stopping in Through Lanes	Mark/lengthen exclusive turn lanes
	Install two-way left-turn lane
	Widen approaches to handle turn lanes
	Increase curb/edge-of-pavement radius
	Add pretimed, protected left-turn signals
	Install signal actuation
	Install dual left-turn lanes, signs, and signals
	Provide lead/lag or split phasing
	Prohibit turns
	Reroute left-turn traffic
Unexpected Slowing and Lane Changing	Install guide signs
	Install larger signs
	Install lane-use control signs (metal)
	Install internally illuminated signs
Narrow Lanes	Eliminate parking
	Widen lanes
Unexpected/ Unnecessary Stops Due to Signal	Revise signal phasing/sequence
	Retime traffic signal
	Upgrade signal controller
	Provide signal progression
	Install signal actuation
	Remove unwarranted signalization
Unsafe Right-Turns-on-Red (RTOR)	Reduce RTOR sight obstructions
	Add right-turn lane channelization
	Provide right-turn overlap (green arrow)
	Prohibit RTOR
Crossing Pedestrians	Add stop bars/crosswalks
	Post PED XING / advance XING signs
	Place advance pavement messages
	Install WALK-DON'T WALK signals
	Add/improve lighting
	Post SCHOOL XING / advance XING signs
	Use crossing guards near schools

Table D4
Possible Causes and Countermeasures for Rear-End/Rear-Right and Sideswipe/Same-Direction Crashes at Signalized Intersections

Cause of Crashes	**Possible Countermeasures**
	Reroute pedestrians to safer crossing
Slippery Surface	Post SLIPPERY WHEN WET signs
	Improve drainage
	Groove pavement
	Resurface roadway
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Poor Visibility of Traffic Signal	Remove signal sight obstructions
	Post SIGNAL AHEAD warning signs
	Install/replace signal visors
	Add signal back plates
	Add/relocate signal head
	Install 12-inch signal lenses
	Install advance flasher-signs
	Upgrade signalization

Table D5
Possible Causes and Countermeasures for Rear-End/Rear-Right and Sideswipe/Same-Direction Crashes at Unsignalized Intersections

Cause of Crashes	Possible Countermeasures
Turning Vehicles Slowing or Stopping in Through Lanes	Mark/lengthen exclusive turn lanes
	Install two-way left-turn lane
	Widen approaches to handle turn lanes
	Increase curb/edge-of-pavement radius
	Prohibit turns
	Reroute left-turn traffic
Unexpected Slowing and Lane Changing	Install guide signs
	Install larger signs
	Install lane-use control signs (metal)
Narrow Lanes	Eliminate parking
	Widen lanes
Poor Visibility of STOP/YIELD Signs	Remove sign sight obstructions
	Install larger signs
	Install STOP/YIELD AHEAD signs
	Construct rumble strips in pavement
Inadequate Gaps for Turning and Accelerating	Change from two-way to all-way STOP
	Signalize intersection
Slippery Surface	Post SLIPPERY WHEN WET signs
	Improve drainage
	Groove pavement
	Resurface roadway
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Restricted Sight Distance	Install intersection warning signs
	Move intersection away from curves/crests
Crossing Pedestrians	Add stop bars/crosswalks
	Post PED XING / advance XING signs
	Place advance pavement messages
	Add/improve lighting
	Post SCHOOL XING / advance XING signs
	Use crossing guards near schools
	Reroute pedestrians to safer crossing
	Signalize pedestrian crossing

Table D6
Possible Causes and Countermeasures for Crashes Involving Wet Pavement

Cause of Crash	Possible Countermeasure
Slippery Surface	Post SLIPPERY WHEN WET signs
	Improve drainage
	Groove pavement
	Resurface roadway
Inadequate Maintenance	Repair/replace roadway surface
	Repair/replace shoulder surface
	Add/improve lighting
Inadequate Pavement Markings	Upgrade markings (halve maintenance cycle)
	Supplement centerline with reflective pavement markers
	Add centerline + edgelines to unstriped road
	Add centerline to unstriped pavement
	Install reflectorized pavement lines
Excessive speed	Post/reduce speed limit
	Increase traffic/speed enforcement

Table D7
Possible Causes and Countermeasures for Crashes Occurring During the Nighttime

Cause of Crashes	Potential Countermeasures
Inadequate Maintenance	Repair/replace roadway surface
	Repair/replace shoulder surface
Inadequate Pavement Markings	Upgrade markings (halve maintenance cycle)
	Supplement centerline with reflective pavement markers
	Add centerline + edgelines to unstriped road
	Add centerline to unstriped pavement
	Install reflectorized pavement lines
Poor Visibility of Traffic Signal	Remove signal sight obstructions
	Install/replace signal visors
	Add signal back plates
	Add/relocate signal head
	Install 12-inch signal lenses
	Upgrade signalization
Poor Visibility at Night	Add/improve lighting
	Install advance-flasher signs
	Install larger signs
	Install roadside post delineators
	Install internally illuminated signs
Poor Visibility of STOP/YIELD Signs	Remove sign sight obstructions
	Install STOP/YIELD AHEAD signs
	Construct rumble strips in pavement
Driver Falling Asleep	Install raised median
	Install flush median
	Add continuous rumble strip to shoulder
	Install barrier curbing
	Install guardrails
Excessive Speed	Post/reduce speed limit
	Increase traffic/speed enforcement
Restricted Sight Distance	Reduce obstructions on insides of curves
	Move intersection away from curves/crests
	Lower roadbed on hill crests
	Flatten roadway curves

Table D8
Crash Reduction Factors (% reduction)

Countermeasure	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9
Install barrier curbing							30		
Add breakaway features to obstacles		44		35	25		55		5
Install guardrails			19	13	30				5
Install impact attenuators		34	41		80		60		5
Install raised median		32			8		25		25
Install flush median		32			8				15
Add right-turn lane channelization				23	30			20	25
Favorably offset opposing left-turn lanes				23	30			20	25
Increase curb/edge-of-pavement radius						15		15	15
Channelize driveway				23	30			20	25
Close/relocate driveways near intersection								13	
Install curb to better define driveway location							10		
Upgrade markings (halve maintenance cycle)									15
Add stop bars/crosswalks							10		25
Place advance pavement messages								10	
Add centerline to unstriped pavement		6		13	65		65	30	35
Add centerline + edgelines to unstriped road		6	30	13	25		25	22	25
Mark/lengthen exclusive turn lanes		27		23	25		25	30	15
Install two-way left-turn lane			30	23		35	40	30	30
Supplement centerline with reflective pavement markers					25		25	5	10
Install no passing zones								40	40
Install roadside post delineators		6		13	30		30	20	30

Table D8
Crash Reduction Factors (% reduction)

Countermeasure	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9
Install reflectorized pavement lines		6		13	20				
Install reflectors on object			16						
Prohibit travel in curb lanes								15	
Reduce obstructions in median		22		31		50	55	30	30
Reduce obstructions on insides of curves		22		31		50	55	30	30
Remove/relocate obstacles close to road		22	61	31	85	50	55	30	30
Remove obstructions from sight triangle		37		31		50	55	30	30
Remove sign sight obstructions		37		31		50	55	30	30
Reduce RTOR sight obstructions		37		31		50	55	30	30
Remove signal sight obstructions		37		31		50	55	30	30
Add/improve lighting		17	19	9	25		25	25	25
Increase traffic/speed enforcement									20
Groove pavement		15		48	21			15	25
Improve drainage			36		30		30		20
Resurface roadway		19		17	21		42	20	25
Repair/replace roadway surface					15		15		
Repair/replace shoulder surface					28				25
Add continuous rumble strip to shoulder			53		27			25	25
Construct rumble strips in pavement					27			25	25
Upgrade roadway shoulders		13	57	29	42	15	12	20	15
Widen lanes			56	25	28	25	30		25
Move intersection away from curves/crests							50		30
Realign opposing intersection legs		44	43		40		50	40	40

Table D8
Crash Reduction Factors (% reduction)

Countermeasure	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9
Provide proper superelevation					65	20	65	40	40
Flatten roadway curves				21	42	25	50	30	40
Lower roadbed on hill crests				21	40		50	45	40
Construct a local service road					40			40	40
Signalize intersection	45	23		18	29		28	20	25
Retime traffic signal								10	10
Increase yellow change interval								30	15
Add all-red clearance interval								30	15
Revise signal phasing/sequence									25
Provide right-turn overlap (green arrow)									25
Add pretimed, protected left-turn signals	41		15		22		25	30	25
Provide lead/lag or split phasing	41		15		22		25	30	10
Install WALK-DON'T WALK signals					13		15		
Signalize pedestrian crossing								15	
Install signal actuation								20	
Provide signal progression (3 intersections)							10		15
Upgrade signalization	49	22		18	25		22	20	20
Upgrade signal controller							22	20	20
Install 12-inch signal lenses								10	10
Add signal back plates									20
Remove unwarranted signalization			100						50
Install advance flasher-signs							50	25	35
Retime WALK-DON’T WALK signals								10	10

Table D8
Crash Reduction Factors (% reduction)

Countermeasure	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9
Add pretimed, protected pedestrian phase								30	25
Install STOP/YIELD AHEAD signs		16		23	47		20	30	30
Post SIGNAL AHEAD warning signs		16		23	35		20	40	30
Install intersection warning signs		16	33	23	35		20	30	30
Post PED XING / advance XING signs		16		23	35		20	15	25
Post SLIPPERY WHEN WET signs		16		23	35		20	20	20
Add two-way STOP/YIELD at urban intersection		16	19	23	59		20	30	35
Add two-way STOP at rural intersection		16	19	23	48		20	30	35
Change from two-way to all-way STOP		16		23	68		20	65	55
Eliminate parking					32		32	30	35
Install guide signs		16		23	35			15	15
Install lane-use control signs (metal)			14						
Install larger signs								15	
Post/reduce speed limit								25	20
Post curve warnings/advisory speeds		16	14	23	35			30	30
Sign one-way street operation									30
Prohibit RTOR					40			40	45
Reroute left-turn traffic									45
Prohibit turns					40			40	45
Install driveway warning signs		16		23	35		20		25
Post SCHOOL XING / advance XING signs		16		23	35		20		15

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APPENDIX E

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- 2.2 Turning Movement Count Data
- 2.3 Crash Data
- 2.4 Base Plan and Illumination Layout
- 2.5 Speed Data
- 2.6 Conflict Studies
- 2.7 Planned Roadway Improvements

3.0 Office Review
- 3.1 Intersection Characteristics
- 3.2 Operational Analysis
- 3.3 Crash Analysis
  - 3.3.1 Crash Occurrences
  - 3.3.2 Critical Crash Analysis

4.0 Field Investigations
- 4.1 Field Investigation Summary
- 4.2 Identification of Potential Hazards
- 4.3 Positive Guidance Review
- 4.4 Traffic Conflict Studies

5.0 Diagnosis of Crash Problem
- 5.1 Crash Severity
- 5.2 Crash Type
- 5.3 Temporal Analysis
- 5.4 Environmental Conditions
- 5.5 Summary of Crash Analysis

6.0 Problem Statement

7.0 Identification of Countermeasures
- 7.1 Countermeasure 1
- 7.2 Countermeasure 2
- 7.3 Countermeasure 3
- 7.4 Evaluation of Countermeasures

8.0 Remedial Measures and Implementation Plan
- 8.1 Remedial Measures
- 8.2 Implementation Plan

9.0 Conclusions and Recommendations