IMPROVED APPROACHES TO MANAGE ROAD SAFETY INFRASTRUCTURE

by

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ABSTRACT

Due to the importance of road safety, most road authorities and safety agencies employ some type of road safety management program, designed to improve the safety performance for the system users. One road safety management program is delivered through road planning and engineering, aimed to improve the road design features to reduce the frequency and/or severity of collisions. These road safety management programs can be divided into two categories: reactive road safety initiatives (i.e., responding to existing road safety problems) and proactive road safety initiatives (i.e., actions taken to prevent the emergence of problems).

There are several problems with the two approaches to deliver road safety. First, deteriorating quality and quantity of collision data, necessary for safety analysis, is jeopardizing the success of reactive safety management programs. Secondly, the inherent nature of a reactive program is problematic (i.e., allowing problems to emerge before treatment) and that the area of influence is limited, responding only to the most problematic locations. A proactive approach to road safety management can address these problems, however a proactive approach is a new concept and suffers from a lack of procedural and evaluation techniques.

The goal of this research work is to explore new opportunities to improve the evaluation techniques and processes used in support of effective road safety management. This work offers four separate contributions that attempt to achieve this goal. First, explore the use of auto insurance claims data for road safety analysis, addressing the problem of a dependency on the deteriorating collision data. Second, develop a subjectively based, observation technique that can be used for road safety analysis, based on a concept of road-user risk, to address the collision data problem. Third, provide a framework and process to support proactive road safety planning, describing how the safety evaluation tools should be applied. Fourth, introduce improved techniques to evaluate proactive road safety management by developing collision prediction models.

Each of the four attempts to improve the evaluation techniques and processes used in support of effective road safety management has proven to be successful, as described in detail in this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

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1.0 INTRODUCTION

The purpose of this chapter is to introduce the research topic, to provide background information necessary to understand the research problem and to suggest the proposed solutions. This introduction is divided into six sections. Section 1.1 provides an overview of typical road safety programs, identifying the need to address the road safety problems. Section 1.2 provides a brief description of the management of road safety, listing the current obstacles and thereby introducing the research problem, as described in Section 1.3. Section 1.4 lists the goals and objectives for the research project and Section 1.5 defines the problem statement and point of departure for the research. The chapter concludes with Section 1.6 detailing the structure of the thesis.

1.1 Background and Overview of Road Safety

Traffic collisions don't 'just' happen, nor are collisions completely 'accidental' and thus the term 'collision' rather than 'accident' is used in this thesis. There are many factors that can contribute to the occurrence of a collision, caused by one or a combination of road system components. Failure of any one or combination of these system components, which include the driver, the vehicle and the road, can result in a collision. Collision prevention can be achieved by targeting the system components and developing mitigative initiatives.

The frequency and severity of motor vehicle collisions are a significant problem. For example, in the Province of British Columbia, there are approximately 100,000 reportable collisions per year in the province (ICBC (1), 1995). A reportable collision is defined as any incident that results in bodily injury or where the property damage exceeds $1000. In addition, there are approximately another 120,000 collisions per year, which are unreported by police but result in automobile insurance claim (Mercer, 1995). This translates into approximately 500 fatal collisions per year, 60,000 serious injury crashes per year, and the balance of 160,000-property damage only collisions per year.

The total cost associated with this yearly toll of motor vehicle collisions is very high. Based on a willingness-to-pay economic model for collision costs (Miller, 1992), the total annual cost of motor vehicle collisions in British Columbia is $7.5 billion (1997 dollars). This willingness to pay economic model assumes a fatal collision cost of $4,170,000, an injury collision cost of $97,000 and a property damage only collision (PDO) of $6,000. Using collision costs derived from the average auto insurance claims (not including the societal costs used in the willingness-to-pay model), the annual cost of collisions is $2.8 billion dollars (this assumes $281,000 per fatal collision, $44,000 per injury incident, $4,500 per PDO incident).

Apart from the economic costs of collisions, there is a considerable social cost with the toll of pain and suffering associated with motor vehicle collisions. For example, the average years of lost life due to a fatal collision is 39.5 years, significantly higher when compared to other health problems such as respiratory disease (9.4 years lost), circulatory disease (10.2 years) or tumors (15.3 years) (CCMTA, 1998). Consequently, reducing the frequency and severity of collisions is of paramount importance to road authorities and safety advocacy groups who are concerned with improving road safety and reducing the economic and societal costs of collisions.

1.2 Road Safety Management

Because safety is considered important for all road users, most road authorities and road safety agencies employ some type of road safety management program, designed to improve the road safety performance for the system users. Safety management programs can consist of numerous initiatives, such as a road improvement or "black-spot" program, vehicle maintenance testing programs, campaigns to stop drinking and driving, speed enforcement programs, the development of road or vehicle safety standards, a road safety research program, or other various road safety programs.

As indicated above, the direction for road safety management can be far reaching. This research will focus specifically on initiatives targeted at improvements to the road, normally addressed through engineering or planning initiatives. Within the confines of initiatives aimed to improve road design and performance, road safety management can be divided into two categories: reactive road safety initiatives (i.e., responding to existing road safety problems) and proactive road safety initiatives (i.e., actions taken to prevent the emergence of problems).

Managing road safety in a reactive manner is an efficient way to improve road safety performance for existing road infrastructure. The cornerstone of most reactive road safety management programs consists of a "black-spot" program, where road improvements are made to existing hazardous locations, called "black-spots". In order to identify and address a "black-spot", a significant collision history must exist before any road improvements are implemented, making this approach reactive in delivery.

The management of road safety in a proactive manner is also considered an effective way to improve road safety performance. Unlike the reactive approach, the intention of proactive road safety management is to introduce road safety concerns early in the road planning and design process in order to prevent collisions from occurring once a facility (new or existing) is built and opened. Attempting to prevent collisions in an explicitly proactive manner is a relatively new approach in the management of road safety.

There are several problems associated with the two different approaches to deliver road safety. This introduction will briefly list the various problems with each approach, leading to the research problem and proposed solutions. A greater description of the problems is provided in Chapter 2, Background and Research Problem.

1.3 Problems in Managing Road Safety

Collision data is critical to the delivery of any road safety management program. Unfortunately in many jurisdictions, the quantity and quality of collision data is susceptible to problems. These problems jeopardize the success and continuance of reactive "black-spot" programs (programs that target high collision locations). Typical problems with the collision data include:

- a reduction in the level of collision reporting due to resource pressures on enforcement officials who collect collision data,
- a deterioration in the quality, accuracy and reliability of the data used to describe a traffic collision,
- a non-systematic reduction (over time) in the quantity and quality of collision data within a jurisdiction,
- the collision data often is not made available in a timely manner, nor in a useful format, and
- in general, the collection, warehousing and distribution of collision data suffers from jurisdictional and bureaucratic obstacles.

Many of these collision data problems exist in British Columbia and the simple solution is to have the police attend and report crashes accurately, consistently, and in an efficient manner. Efforts in this direction have taken place since problems emerged in 1995, but to date no progress has been made to resolve these problems. Therefore, alternative data sources and evaluation techniques are required to reduce the dependency on the provincial collision data in British Columbia.

There are other problems associated with reactive "black-spot" programs. One inherent obstacle is that a significant problem must develop and exist before any mitigative actions are taken. Allowing problems to develop and then reacting to that problem is costly as compared to an approach that attempts to prevent collisions before a facility is opened.

Another problem is that the area of influence or coverage of road improvements is limited to the "black-spot" locations, with the remaining network excluded from consideration. As a result, a large portion of the network, some experiencing poor safety performance, is not treated.

To counteract the problems associated with a reactive approach to road safety, it is suggested that a proactive approach may address and possibly resolve many of these obstacles. However, a proactive approach to road safety can also suffer from some technical and logistical obstacles.

One obstacle associated with the delivery of proactive road safety is the lack of process and opportunity to explicitly consider road safety issues. Historically, the road planning process rarely allows planners to consider the impacts of planning decisions on safety, believing that road safety concerns will be accommodated in subsequent design stages through the application of road design standards.

There is also a lack of the necessary tools to evaluate road safety in a proactive manner. This obstacle is characterized by a lack of a credible and consistent method to estimate the impact on road safety performance arising from a planned improvement. This may be due in part, to a lack of guidance for practitioners and the presence of poorly defined road safety standards in relation to the impact on road safety performance.

Related to the lack of evaluation tools for proactive road safety, is the problem of a lack of understanding of the relationships between road feature (geometric design element) and the frequency and/or severity of collisions. Without a clear understanding the relationships between road design feature and safety, it is difficult to provide the necessary arguments in defense of planned improvements in support of road safety.

To summarize, poor collision data is jeopardizing the success of reactive safety management programs and alternate data sources and techniques are required to resolve this problem. The inherent nature of a reactive road safety program is problematic and a proactive approach can address this and other problems. However, a proactive approach to road safety is a new concept and as such, suffers from a lack of procedural and evaluation techniques. This research will address these problems.

1.4 Proposed Improvements for Road Safety Management

This section describes the goals and specific objectives for this research project, aimed to address the obstacles associated with the effective management of road safety. Real-life case studies are used to demonstrate the developments and applications produced by this research.

1.4.1 Goals of the Research

The first goal of this research is to explore the use of auto insurance claims data for road safety analysis in order to address the problem of a dependency on the deteriorating collision data. The usefulness of claims data for road safety evaluation will be demonstrated with the development and introduction of a Claim Prediction Model (CLPM). The claim prediction model will be developed based on auto insurance claim data available through the Insurance Corporation of British Columbia (ICBC) and from road data available through municipal road authorities.

The second goal of this research project is to develop a subjectively based, observation technique that can be used for road safety analysis and evaluation. A process to derive a road safety risk index (RSRI) will be developed based on a concept of road-user risk. Similar to the use of claims data, the RSRI is developed to address the problem of a dependency on collision data and to assist in road safety performance evaluation.

The third goal of this research is to provide a framework and process to support proactive road safety planning and design. In order to provide comprehensive and proactive road safety management, a strategic framework will be formulated, describing how the safety evaluation tools should be applied. This strategy should provide the necessary direction for road safety research, based on the priorities consistent that are with overall road safety objectives.

The final goal of this research is to introduce new and improved techniques to evaluate road safety by developing collision prediction models (CPMs). Application of the developed collision prediction models will improve the quality and reliability of road safety management programs. In addition, the CPMs will provide reliable estimates for the safety performance associated with planning and design decisions, thereby solving the problem of a lack of tools required in the delivery of proactive road safety management.

1.4.2 Objectives of the Research

In order to achieve the goals listed above, a number of specific objectives have been formulated for this research. These specific objectives are listed in point form below.

Background Information and Literature Review

1) It is necessary to undertake a thorough literature review of the topics associated with this research. Chapter 2, entitled Background and Research Problem, provides a detailed review of the research problem and related information. In addition, a literature review associated with each specific research topic is provided at the beginning of each chapter. These reviews include the use of auto insurance claim data for road safety evaluation, a review of subjective road safety evaluation techniques, a review of proactive safety planning and design, and a review of collision prediction models.

Claim Prediction Models (CLPMs):

1) Obtain and compile the data required for the development of a claim prediction model for signalized intersections in the Lower Mainland area of British Columbia. This data includes the auto insurance claims data, the traffic volume data, and other data that is reliably collected and defines the road character at each signalized intersection.

2) Once the data is compiled, develop a claim prediction model (CLPM) using the Generalized Linear Regression Modeling software (GLIM) and comment on the usefulness and limitations of the model.

3) Demonstrate the application of the CLPM by identifying and ranking problematic intersections, thereby satisfying the needs of a reactive "black-spot" program. Investigate and compare the results produced from the claims prediction model with historical collision records at the sites. Comment of the usefulness and application of CLPMs for road safety analysis and identify any deficiencies and future research needs.

Road Safety Risk Index (RSRI):

1) Develop the procedures to collect data that can be used to evaluate the road safety risk. This data is intended to supplement or replace existing data and address the alarming deficiencies in the collision data. This data will target specific safety issues associated with the design elements of urban and rural corridors. The data collection procedure will be tested by collecting road safety risk data for a rural highway located in the Thompson-Okanagan district of the province.

2) Test the reliability of the data collection process by determining the replicability of results produced by different observers. A high level of agreement between observers will validate the process, ensuring reliability of the data collection process.

3) Use the road safety risk data to develop a Road Safety Risk Index (RSRI) that can be used to identify and rank problematic road sections. Provide comment on the usefulness and limitations of the risk index, with respect to the use in a reactive road safety management program.

4) Investigate and compare the results produced by the RSRI with an objective measure based on the historical collision frequency on the case-study corridor. Comment on success of the RSRI by investigating the correlation between the risk index and the collision history.

Framework for Proactive Road Safety Planning

1) Conduct a literature search to understand information and tools related to proactive road safety, and utilize useful concepts in the development of a framework and procedures for proactive road safety planning.

2) Identify the opportunities to provide explicit safety input within the road planning process. Develop some guiding principles based on minimizing the road-user risk and test the effectiveness of the processes by applying the framework to a real-world case study: the planning and reconstruction of the Cape-Horn – Port Mann Bridge Interchange.

3) Comment on the success and limitations of the proposed framework in delivering proactive road safety. In addition, identify future research that will improve this new approach to road safety.

Collision Prediction Models (CPMs):

1) Obtain and compile data that can be used to develop collision prediction models (CPMs). This data includes the collision data, traffic volume data, or any other data that is reliably collected and accurately defines the roadway character.

2) Once the data is complied, develop a series of collision prediction models using Generalized Linear Regression Modeling software (GLIM) and comment on the quality of the models.

3) Demonstrate the usefulness of the CPMs in satisfying the needs of a proactive road safety program by demonstrating an application of how a collision prediction model can be used to support proactive planning initiatives.

1.4.3 Case Studies: CLPMs / Risk Index / CPMs / Safety Framework

Several case studies are used to validate the results produced by the various components of this research and to demonstrate the usefulness of the results in real-world applications.

The first case study involves a group of signalized, urban intersections located within the municipalities of Vancouver and Richmond in the Lower Mainland area of BC. These locations are similar in character and are used to develop the claim prediction model (CLPM). Each intersection has four approaches with the traffic volume known for each approach. A greater description of the study locations will be provided in a subsequent section of this thesis.

The second case study is a provincial highway corridor that is currently targeted for a major planning review by the BC Ministry of Transportation and Highways within the Corridor Management Planning Program. The corridor is Route 1, the Trans Canada Highway, from Kamloops to the Alberta border, approximately 450 kilometers in length. The route is considered the principle east-west provincial route for ground transportation, linking British Columbia with the rest of Canada. This corridor is used for the development and application of the road safety risk index (RSRI) as well as for the development and application of the collision prediction models (CPMs).

The third case study involves the planning and re-construction of a major urban interchange in the lower mainland area of BC. The Cape-Horn and Port Mann Bridge area is a significant transportation node for traffic movement and is currently under a planning review by the BC Ministry of Transportation and Highways. This important planning project is used to demonstrate the proactive road safety framework and procedures to explicitly consider road safety needs.

1.5 Problem Statement and Point of Departure

Several obstacles associated with the management of road safety have been presented in this chapter. These obstacles define the problem statement for this research endeavor, which is as follows:

> *To explore new opportunities to develop and improve the evaluation techniques and processes that can be used in support of effective road safety management.*

This research offers four separate contributions that attempt to address the problem statement and define the point of departure for this research work. Each contribution is described in a Thesis chapter, summarized as follows:

Chapter 3: Explore the use of auto insurance claims data for road safety analysis in an attempt to address the problem of a dependency on the deteriorating collision data.

Chapter 4: Develop a subjectively based, observation technique that can be used for road safety analysis, based on a concept of road-user risk, to address the problem of a dependency on collision data.

Chapter 5: Provide a framework and process to support proactive road safety planning and design, describing how the safety evaluation tools should be applied.

Chapter 6: Introduce new and improved techniques to evaluate road safety by developing collision prediction models to address problems with reactive and proactive road safety management.

1.6 Structure of Thesis

The thesis is divided into eight chapters. This first chapter has provided an introduction to the thesis by including background information, an overview of the problem, the goals and objectives set out for the research, and the point of departure. Chapter Two provides greater background information related to road safety management and expands on the research problem. Chapter Three describes the data and methodology used to develop the claim prediction model (CLPM) and demonstrates the application of the CLPM. Chapter Four describes the process to collect road safety risk data and how the data is used to develop a road safety risk index (RSRI). The chapter also includes the validation of the risk index. Chapter Five presents a framework and process that are developed in support proactive road safety planning activities. Chapter Six describes the data and methodology used to generate the collision prediction models (CPMs) and demonstrates the usefulness of CPMs for road safety management. Chapter Seven provides some conclusions and recommendations from the research, including the contributions made by the research. Chapter Eight concludes the thesis by offering some suggestions on future research that could be completed to advance the contributions made by this research effort.

2.0 BACKGROUND AND RESEARCH PROBLEM

The purpose of this chapter is to simply expand on the background information provided in the Introduction and to provide a general review of the management of road safety. This chapter describes the magnitude of the road safety problem, the details regarding how road safety is currently managed, and the problems associated with the delivery of road safety management. It is noted that instead of a thesis chapter dedicated to a comprehensive literature review, that each subsequent chapter contains a literature review that is specific to the topic of the chapter.

2.1 The Road Safety Problem

The problem of traffic crashes has been recognized as an important issue worldwide. The American Association of State Highway and Transportation Officials (AASHTO, 1992) recognizes that during an average life-span of 75 years, that 1 out of 84 persons will die violently in a motor vehicle collision and more than 50% will suffer an injury as a result of a collision. Worldwide, 700,000 persons die annually in motor vehicle collisions and as a result, the World Bank is leading a multi-jurisdictional effort to prevent collisions (Silcock and Ross, 1999). A report by the Red Cross (Ross, 1999) reports that the traffic collision situation is an international disaster, and if the trend continues until the year 2020, health departments will be spending approximately 25% of their budgets on traffic collision casualties.

Like the rest of the world, motor vehicle collisions are a significant problem in the Province of British Columbia. According to collision records from 1995, a total of 93,483 reportable traffic collisions occurred on BC roadways. This total number translates into 411 fatal collisions, 32,679 injury collisions and 60,393 property-damage-only incidents (ICBC (1), 1995). This means that on average (in 1995), a fatal collision occurred once every 17.7 hours and an injury causing collision occurred every 11.1 minutes. A collision is reportable in BC if the collision results in personal injury (or death), or the total property damage exceeds $1,000.

In addition to the reportable collisions there are many more collisions that occur but are not reported by (or to) the police. These collisions result in automobile insurance claim and represent a large portion of the total collisions (Mercer, 1995). The differential in reporting levels between reportable collisions and claims is more prevalent at the lower severity levels ("fender-benders"). Greater detail of auto insurance claims versus collisions is provided in Chapter 3.

The total cost of collisions is very high, but variable depending on the economic costing model used, as determined by Elvik (Elvik, 1995) in a review of collision costs in 20 motorized countries. Krupp (Krupp et-al., 1993) categorized the valuation techniques into three groups including the cost of compensation, a human-capital cost approach based on human production minus consumption, and a willingness-to-pay approach. Based on a willingness-to-pay model developed in BC (Miller, 1994), the total annual cost of collisions is $7.5 billion, based on $4,170,000 per fatal, $97,000 per injury and $6000 per PDO collision. A compensation model based on auto insurance claim costs produces an annual cost of $2.8 billion dollars ($281,000/fatal, $44,000/injury, $4,500/PDO incident).

Included in a willingness-to-pay collision cost model, is a considerable social cost resulting from the pain and suffering associated with collisions. The average years of lost life due to a fatal collision is 39.5 years, significantly higher when compared to other health problems such as respiratory disease (9.4 years lost), circulatory disease (10.2 years) or tumors (15.3 years) (CCMTA, 1998). Unfortunately, there seems to be public acceptance of the pain and suffering associated with collisions, due to the belief that collisions are 'accidental' and therefore unavoidable. In contrast, a violent crime that results in a death is often given considerably more 'attention' and priority as compared to a fatal collision.

Given the road safety problem, it is not surprising that reducing the frequency and severity of collisions is of paramount importance to road authorities and safety advocacy groups who are concerned with improving road safety and reducing the economic and societal costs of collisions.

There are agencies at all levels of government that are interested in improving road safety. In Canada for example, there are federal agencies such as Transport Canada that have a mandate to assure that road safety is maintained on national routes. As well, each province has an authority that is responsible for the safe operation of provincial routes. Municipalities are also concerned with road safety and many have similar objectives to federal and provincial authorities in terms of preventing or reducing the frequency of collisions. The province of BC is somewhat unique by having another road safety partner, the Insurance Corporation of British Columbia (ICBC), who have an obvious business interest in reducing the frequency of collisions. These authorities deploy numerous initiatives to combat the road safety problems.

2.2 Managing Road Safety

Initiatives to address or manage road safety are generally categorized into three main areas; driver related issues, vehicle-related issues and road-related issues. Driver related improvements usually involve actions that can affect a motorist's driving ability or behavior such as education and enforcement programs. Vehicle improvements include innovations to automobile design that can improve the level of safety for vehicle occupants such as the introduction of seat belts or air bags. Road related improvements involve changes to the design and character of a roadway, resulting in safer or a more forgiving road environment.

Improvements to road safety have traditionally been delivered through three distinctly different campaigns: driver education, enforcement activities and engineering initiatives. Education programs target at the driver in an attempt to improve driver skill or behavior, as the driver represents up to 92 percent of the 'blame' in collisions as illustrated in Figure 2.1 (Rumar, 1985). Enforcement activities target drivers and involve activities that govern or regulate motorized travel and include a penalty for non-compliance. Engineering initiatives are usually targeted at road or vehicle related issues, where improved design elements can result in an improvement to the road safety performance.

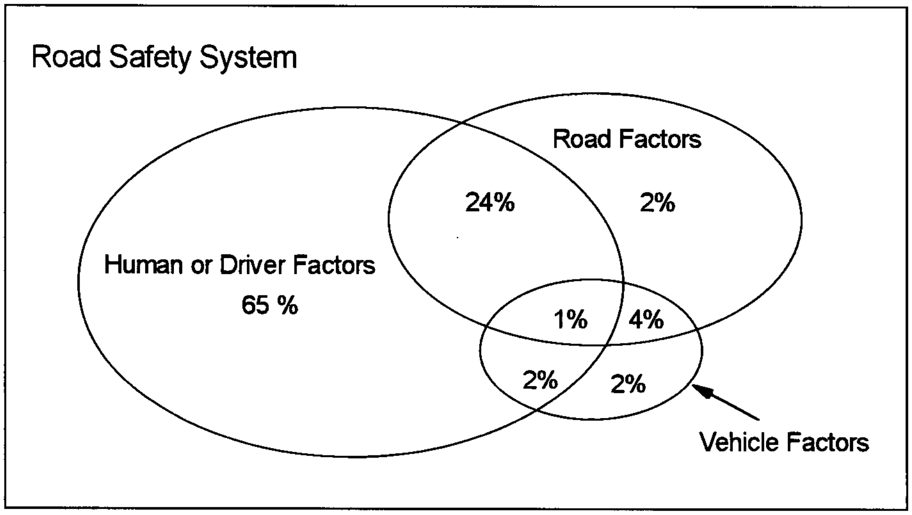

Figure 2.1 Collision Contribution by System Component (Rumar, 1985)

Most road authorities and road safety agencies employ some kind of road safety management program, designed to target one or many components of the system (the driver, the vehicle, or the road) as shown in Figure 2.1. Safety management programs can consist of numerous initiatives such as a "black-spot" program (this program targets high collision locations), vehicle maintenance testing, campaigns to stop drinking and driving, speed enforcement programs, the development of road and/or vehicle safety standards, a road safety research program, or other various safety programs.

The Land Transport Safety Authority of New Zealand developed a good example of a comprehensive road safety management program. In this program, the first step of the road authority is to target drivers by focusing on poor behavior, speed control, alcohol use, occupant restraints, fatigue, young drivers, old drivers, and the needs of special road users. Secondly, the program targets safer roads by focusing on road design standards, construction and maintenance policies, traffic control and management, and a systematic, comprehensive black-spot program. The third component of the program is to target vehicles by focusing on vehicle standards, new vehicle technology, and vehicle inspection programs. Finally, the road authority has an overall safety management program, including strategic planning, research and evaluation, and safety audits (Land Transport, 1994).

Most road authorities do **not** have the range of responsibility or jurisdiction to enact a safety management program similar to that in New Zealand. For example in BC, the Ministry of Transportation and Highways has jurisdiction for improvements to provincial roads, ICBC has jurisdiction over driver regulation and education, and the Ministry of the Attorney General controls the road safety enforcement initiatives. Unfortunately, there is a lack of co-ordination between the different of road safety initiatives, reducing the overall effectiveness of safety programs. The focus of this research is on initiatives undertaken to improve the physical character of a road, generally undertaken by road authorities or ICBC.

2.2.1 Reactive Road Safety Management

The cornerstone of most safety management programs consists of a "black-spot" program, often organized within a road authority's rehabilitation program since the improvements are made to existing hazardous locations, or "black-spots". In these programs, a significant collision history must exist and be identified before road improvements are recommended. The BC Ministry of Transportation and Highways (MoTH) has a program called the Highway Safety Improvement Program (HSIP), designed to improve the safety of problematic locations. This program involves a seven-step process, grouped into two stages: the Safety Inventory Stage and the Annual Safety Program Cycle Stage (Ministry, 1999).

The first step of MoTH's safety program is to identify collision-prone locations (or black-spots) by querying a collision database. Step two is to diagnose each problematic site to determine the causal factors for the poor performance. The third step involves developing improvement strategies designed to address the deficiencies at each site. Step 4 involves the selection of the most effective option based on collision prevention benefits. Step five allocates each project into a program category and determines if funding partnerships are available to support the project. Step six involves the development of the annual program given the available budgets and the merit of cost-sharing opportunities. The final step is the implementation, evaluation and monitoring of the program.

A flow chart showing the sequential process of MoTH's Highway Safety Improvement Program (HSIP) is provided below in Figure 2.2. It is noted that the process and elements of MoTH's safety program is very similar to many other road safety improvement programs.

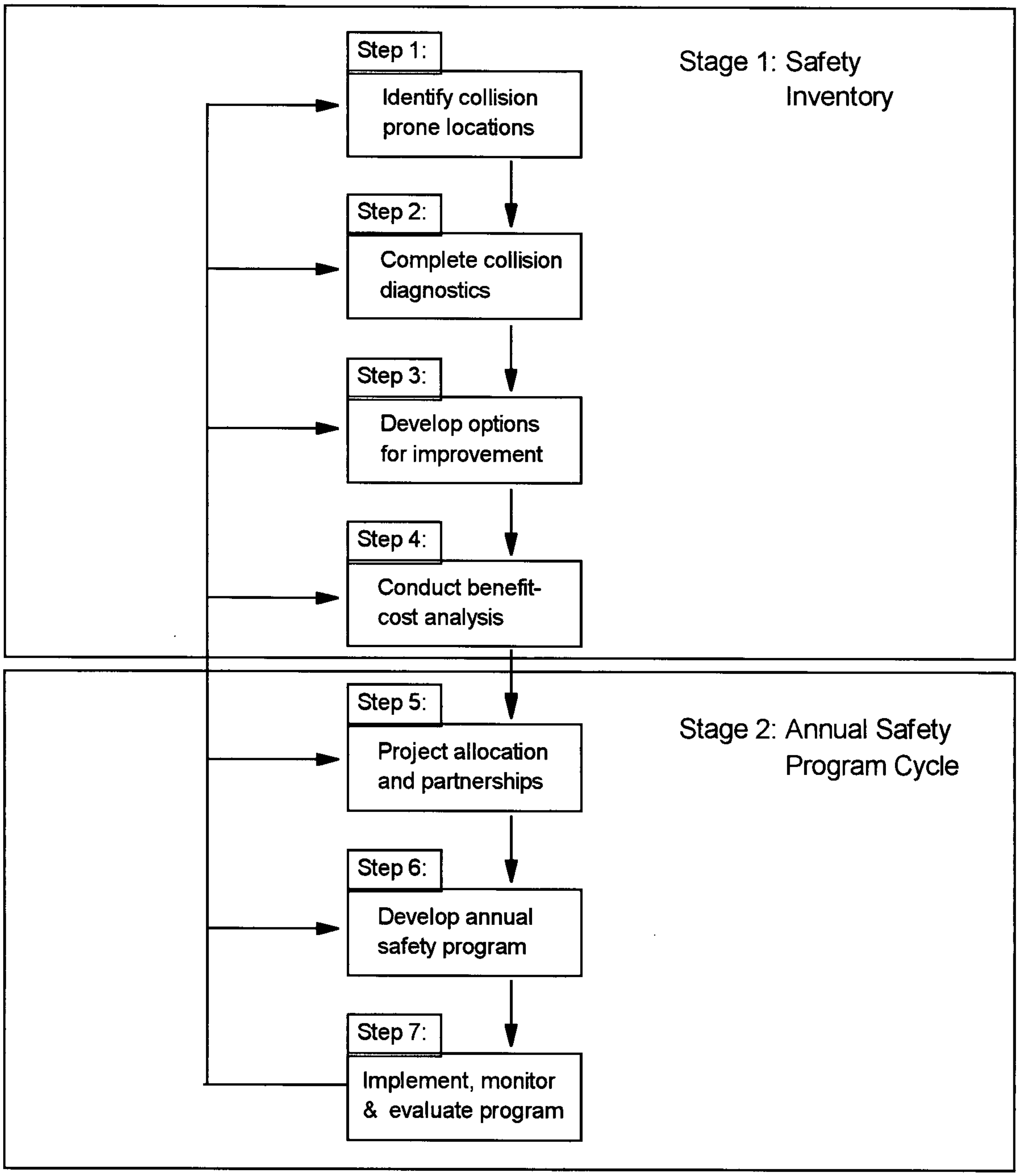

Figure 2.2: Flowchart of MoTH's Highway Safety Improvement Program Interim Highway Safety Program Manual, (Ministry, 1999)

2.2.2 Proactive Road Safety Management

In recent years, attention to the management of road safety has gained prominence in the area of road planning. Planning initiatives operate within a road authority's capital program, in contrast to the reactive black-spot program, which normally operates within a rehabilitation program. The intention of introducing a focus on road safety early in the planning process is to prevent collisions from occurring once a new facility is opened or rebuilt. Consequently, this is a proactive approach to road safety.

However, explicitly addressing road safety concerns early in the planning stages is somewhat limited. Currently, there are several general 'rules-of-thumb' that may be considered in the planning process to address road safety performance. For example, an increase in the functional classification (i.e., the planning of an arterial road to be reconstructed to an expressway) will improve the road safety performance, or that two staggered T-type intersections are safer that one four-leg intersection. Unfortunately, there is a lack of a systematic process and methodology to address road safety needs within planning and often an accurate assessment of safety needs is not realized. This obstacle will be described further in a subsequent section.

The explicit consideration of safety issues has also recently occurred within the road design stages. In the past, road safety issues were often considered in an implicit manner, such that if the design standards were met, then it was assumed that all safety concerns would be satisfied. With the exception of large-scale projects, a safety engineer would rarely have the opportunity to review and approve designs. Unfortunately, without an explicit and focused attention to road safety issues, the selection of road design standards (minimum or not) may often result in a less than satisfactory level of safety for a new facility. This problem stems from the fact that many road design standards were not developed based on an understanding between geometric road design feature and the frequency and severity of collisions. Rather, road design standards were developed based on what was assumed to be reasonable and affordable (Professional, 1997).

A real-world example that demonstrates the hazards with the strict application of road design standards is the recently completed 407 Highway in Ontario. In 1996, the Ministry of Transportation of Ontario completed the up-grade of Highway 407, a major corridor in the province. In order to control construction costs, several minimum design standards were selected. However, before the Highway was opened to the public, an inspection was completed and it was believed that the compounding effects of several "compromised" design standards would reduce the overall safety performance on the highway. As a result, considerable study and improvement were required, resulting in a delay to the opening and a slight increase in cost to the project (Professional, 1997).

Another example of how safety is becoming explicitly considered in the road design stages is the new Transportation Association of Canada's design manual, entitled, Geometric Design Guide for Canadian Roads (TAC, 1999). In this national design guide, several road safety functions are provided for the designer, such that the safety implications of a specific design decision can be evaluated in terms of its effect on safety, measured by the expected frequency of collisions. An advantage of this approach is that it allows road designers to have an opportunity to make more-informed, reasonable and cost-effective design decisions. This is in sharp contrast with previous design guides that simply provided a table of values for specific design features, often based on road classification or design speed, and designers were frequently reduced to 'table-pickers', not really designing nor necessarily understanding the impact of design features on safety performance.

There are many opportunities to deliver proactive and preventive road safety through the application of safety conscious planning and design concepts, one of the focuses of this research. The Provincial Highway Plan (PHP) and the Corridor Management Plans (CMP) are two examples of capital planning initiatives, undertaken by the British Columbia Ministry of Transportation and Highways, where explicit attention to road safety concerns is required and should be beneficial in realizing the Ministry's road safety mandate.

2.2.3 Road Safety Data

The foundation for measurement in most road safety initiatives is motor vehicle collision data. Collision data can come from a wide variety of sources including enforcement officials or emergency response personnel who often attend motor vehicle collisions. Collision information can also be obtained from auto insurance claim data, from site and causal data collected by road authorities, from self-reports offered by those involved in the incident, from hospital reports of collision victims and other data streams. The data elements can vary significantly between reporting agencies, but generally can be categorized into driver data, vehicle data, road data, and environmental data. The quantity and quality of the motor vehicle collision data is dependent upon the agenda and needs of the various reporting agency or source.

In British Columbia, a form called the MV104 is the principle tool used by police officials to collect information concerning traffic collisions. The form contains approximately 100 data elements that describe the characteristics of a collision, including information of the persons involved, vehicle data, roadway data and environmental information. Examples of the form and the associated template of codes are provided in Appendix 1. This collision data is contained in a central database, called the Traffic Accident Database (TAS) under the responsibility of the ICBC, formerly the provincial Motor Vehicle Branch. Various provincial municipalities and the Ministry of Transportation and Highways then retrieve specific collision data to cover each authority's jurisdiction.

This research will use safety data from many sources. Collision data from the Traffic Accident System (TAS) will be used for the provincial highways, extracted from a sub-system of TAS, called the Highway Accident System (HAS) maintained by MoTH. In addition, auto insurance claim data from the Insurance Corporation of British Columbia will also be used as a source of safety data, described further in Chapter 3. The road character data is also used as a surrogate to evaluate road safety, as described further in Chapter 4.

2.3 Obstacles in Road Safety Management

In recent years, due to growing interest in road safety, significant advances have been made in road safety engineering. These advances have included the development of improved techniques to identify and diagnose collision prone locations (Sayed, 1995), improved methodology to conduct road safety audits (Navin, 1998, Proctor and Belcher, 1990) and sophisticated evaluation tools such as simulation models and expert systems. These advances improve the evaluation and management of road safety. However, there are still several obstacles that are inhibiting the future direction of road safety.

2.3.1 Obstacles with Reactive Road Safety

There is an inherent obstacle in delivering road safety in a reactive manner. To be effective, significant road safety problems, evidenced by a high frequency of collisions, must exist before hazardous locations can be identified and remedial actions taken to improve safety performance. Allowing a collision problem to develop and then reacting to that problem is costly as compared to an approach that attempts to prevent collisions before a facility is built. Thus, a proactive approach to delivering road safety is expected to overcome this obstacle.

Another problem with delivering road safety in a reactive manner is that the area of influence or coverage is minimal. By design, black-spot programs only target a small percentage of a road network, the most problematic as defined by safety performance thresholds such as collision frequency or rate. Often, great expense is required to improve the most problematic locations, thereby eliminating the opportunity to invest in less problematic locations. As a result, the majority of a road network, some experiencing poor road safety performance, will be ignored.

One final problem with a reactive approach to road safety is that the success of a black-spot program is highly dependent upon a reliable and accurate database of collisions. This obstacle will be described further in Section 2.3.3, but the provincial collision database has significant problems that are jeopardizing the success and continuance of reactive, black spot programs.

2.3.2 Obstacles Associated with Proactive Road Safety

There are some considerable obstacles associated with a reactive approach to road safety and to counteract these problems, it is suggested that a proactive approach to road safety may address and possibly resolve many of these obstacles. However, a proactive approach to road safety also suffers from some technical and logistical obstacles.

One obstacle associated with the delivery of proactive road safety is the lack of process and opportunity to explicitly consider road safety issues. Historically, the road planning process rarely allows planners to consider the impacts of planning decisions on road safety. Rather, planners assume that specific safety issues will be addressed in the design stages. At the design stage, road designers rarely explicitly consider safety needs, assuming instead, that road safety needs are addressed implicitly through road design standards. Today's current economic environment of budget reductions and severe fiscal restraint often leads to the selection of minimum (or below minimum) road design standards (Professional, 1997). Consequently, road safety needs are often compromised due in part, to the lack of a process to explicitly consider safety needs.

There is also a lack of the necessary tools to evaluate road safety in a proactive manner. This obstacle can be characterized by a lack of a credible and consistent method to estimate the impact on road safety performance arising from a planned road improvement. This may be due in part, to a lack of guidance for practitioners and the presence of poorly defined road safety standards. For road safety decisions to be made early in the planning or design stage, it is important to understand the impact of a planned improvement on the safety performance. Unfortunately, a reliable and systematic approach to evaluate the safety impact of road improvements is not currently in use and as such, the ability to comment and influence the pre-implementation success of many road safety initiatives is inhibited. This limitation may lead to some criticism of such initiatives.

Related to the lack of the evaluation tools for road safety, has been a problem of a lack of understanding of the relationships between road feature (geometric design element or road characteristic) and the frequency and/or severity of collisions. There has been considerable research undertaken to develop collision prediction models, but unfortunately the application of these models has not adequately reached the practitioner. A related obstacle is the need to develop predictive models that reflect local conditions because often the available predictive models do not transfer well between jurisdictions.

One final obstacle in the effective delivery of proactive road safety initiatives, is the lack of readily available data of road characteristics. This data includes any road information which can be used to evaluate safety performance, such as horizontal or vertical curve, road surface roughness, the potential hazard of a roadside, problems related to access onto a roadway, and so on. Many road authorities do not warehouse the road character data in an efficient manner and as such, it becomes difficult to obtain and analyze the data. In addition, often the most useful data is that data that is somewhat subjective and acquired directly as a result of road safety concerns.

2.3.3 Obstacles Associated with Road Safety Data

Good quality collision data is critical to the delivery of most road safety management programs. However, in many jurisdictions including BC, the collision reporting practices are not stable over time. For example in BC, a systematic change in the reporting levels occurred in 1991, when the threshold for a property-damage-only collision increased from $400 to $1000, thus reducing the frequency of reported incidents. More problematic however, is that the collision data in the province has been degrading in recent years, and degrading in an inconsistent manner. For example, the number of police attended and reported collisions on BC highways reduced from 21,375 in 1995, to 15,465 in 1996 (a 27% reduction), reducing further to 10,767 in 1997 (a 49% reduction when compared to 1995).

The timeliness and availability of collision data also presents problems for the management of road safety. For example, the database of collision records in BC is normally one to two years behind the current date, thus marginalizing the usefulness of the collision data. Some recent progress has been made in reducing the time lag, but this progress may be a result of the reduced reporting levels as described previously.

In general, the availability of good collision data in BC suffers from technical and bureaucratic obstacles. The technical difficulties involve the consolidation of the various data streams into a comprehensive database, but this problem could likely be resolved given that the appropriate level of resources was devoted to problem resolution. However, the availability of more resources does not seem probable in the immediate future and the problems will likely exist for some time. The bureaucratic obstacles are more difficult to overcome because of political and territorial disputes.

It should be stated that although there are numerous problems with the collision data, there are 'pockets' of consistently reported, reliable and accurate collision data. At these locations, police officials give a high priority to traffic enforcement and recognize the value of collision data. These locations can be used to judge the inadequacy other locations, and can be used to develop tools to assess safety performance.

2.4 Summary

This chapter has expanded on the introductory chapter and provided a detailed description of the problems with road safety management. These include problems with reactive road safety initiatives, proactive road safety initiatives and the quality of collision data. Each of the following four chapters attempts to address these problems by developing new and innovative processes and techniques in support of improved road safety management.

3.0 CLAIMS DATA FOR ROAD SAFETY EVALUATION

Significant problems with the collision data were described thoroughly in the previous sections of this thesis. These collision data problems can inhibit the ability of road safety engineers to identify hazardous locations, to diagnose safety problems, to develop options to improve road safety, to evaluate road safety improvements and to conduct road safety research. Since problems with the collision data are not likely to be resolved in the near future, it is necessary to explore alternate means to evaluate road safety performance. This chapter presents one opportunity to use an alternate source of information to evaluate road safety; namely, the data from auto insurance claim records.

This chapter describes an initial attempt to utilize auto insurance claims records in road safety evaluation by developing a claim prediction model. The model will provide an estimate of the number of auto insurance claims that can be expected at signalized intersections in the Vancouver area of British Columbia. The claim prediction model relates traffic volumes to claim frequency and is developed and used in road safety engineering analysis to identify and rank hazardous locations. These results are then compared to the hazardous locations identified by collision records. A discussion of the usefulness of the claims data will be provided with a recommendation on how the claims data could be utilized in the future.

3.1 Background and Literature Review

An alternate source of data that characterizes the events of a collision are the records available from an auto insurance claim. In settling an auto insurance claim, a claim adjuster must make an assessment of the circumstances of the event, thereby recording important contributing factors that led to the occurrence of the collision. In many jurisdictions in North America, the auto insurance companies are privately owned and obtaining claims data would be difficult, if not impossible. However in British Columbia, a public auto insurance company known as the Insurance Corporation of British Columbia (ICBC), handles most auto insurance claims and centrally warehouses all of the claims data. As such, there is an opportunity to evaluate the usefulness of claims data in road safety engineering analysis.

Due to the uniqueness of a public auto insurance corporation, there is very little in the literature that describes the use of claims data for road safety engineering. Some effort has been made by ICBC to try and relate claims data to collision data. Mercer (Mercer, 1995) developed a series of multipliers to try and relate the number of claims (incidents) received by ICBC to the number of police reported collisions. The number of incidents is presented in Table 3.1, showing that the multiplier increases with a reduction in the collision severity. This is an expected result, as police are more likely to attend and report a serious collision in contrast to a minor 'fender-bender'. The results also indicate a change over time, reflecting the change in the police reporting practice (reducing in recent years).

Table 3.1: Multipliers to Relate Auto Insurance Claims to Reported Collisions

Severity Level		Incident Claims and Police Reported Collisions by Year						
		1993	1994	1995	1996	1997	1998	Total
Fatal Collision	Claims	461	443	448	417	387	389	2545
	Collisions	442	458	411	357	340	365	2373
	Multiplier	1.04	0.97	1.09	1.16	1.14	1.07	1.07
Injury Collision	Claims	49,546	53,581	57,401	59,442	57,244	58,417	333,631
	Collisions	32,393	33,337	32,679	27,146	21,064	19,948	166,569
	Multiplier	1.53	1.61	1.76	2.19	2.72	2.93	2.01
Property Damage Only	Claims	151,899	153,709	170,208	193,808	202,870	209,145	1,081,639
	Collisions	60,984	63,362	60,393	40,785	26,981	22,097	274,607
	Multiplier	2.49	2.43	2.82	4.75	7.52	9.46	3.94
Total	Claims	201,906	207,733	228,057	253,667	260,501	267,951	1,419,815
	Collisions	93,819	97,157	93,490	68,288	48,385	42,410	443,549
	Multiplier	2.15	2.14	2.44	3.71	5.38	6.32	3.20

After a collision occurrence, the auto insurance claimant will report their claim to ICBC, either in person at a claim centre or over the telephone through the Dial-A-Claim Centre. ICBC's claim representative will obtain the initial claim information, opening a new claim on a CL-75 form (Initial Claim Record and Adjuster's Report). Once a new claim is opened, considerable information is obtained from the claimant by the claim adjuster regarding the collision. This includes driver-related information in an attempt to understand the behavior and condition of the driver at the time of the collision. Vehicle damage is assessed by conducting an inspection to determine if any vehicle-related feature may have contributed to the collision (i.e., defective brakes or steering). Finally and if considered important, information is obtained regarding the driving environment at the time of the collision. This could include the roadway surface condition, traffic or road characteristics, road design issues or any other issue contributing to the collision occurrence. In essence, this exercise attempts to answer the 'who', the 'what', the 'how', the 'where', the 'when' and the 'why' questions concerning a collision.

The time lag between a collision occurrence and the time the data is entered into the claims database is very short, with over a 90% completion rate within 15 days (ICBC (2), 1999). This is considerably better than the police reported collision data, where the 90% completion rate is not available until approximately 90 days. Furthermore, the 90 days is an average process time, and excludes the high variability in the time lag from the collision occurrence to the police submission of the collision form to ICBC (this can be several more months).

This information is stored in a central database, called the Claims Reporting Information System (CRIS) maintained by ICBC. This system is designed to store and process auto insurance claims and as such, the system is not particularly useful for road safety assessment or engineering diagnostics. Consequently, the information available in the claims database is more useful in settling claims than in undertaking engineering analysis and therefore, extracting specific information to assist in engineering efforts is problematic.

Obtaining meaningful auto insurance claims data in a useful format is a significant challenge for ICBC staff interested in evaluating road safety. Perhaps the greatest challenge is the lack of information detailing the specific location of an incident. This stems from the lack of a universal location referencing system and the difficulty in extracting this information from a phone-in claim. The location of the incident and other important incident information is not efficiently warehoused in the database. In fact, records are largely comprised of free-form text that does not support significant querying or processing. As such, the claims data becomes difficult to manipulate and extract. Currently, ICBC is undertaking a project referred to as the Crash-Crime-Contravention Project (CCC Project) that is attempting to resolve the data issues, with the goal to better serve road safety needs. A successful project should yield useful information that can be easily extracted and manipulated.

The preceding paragraphs describe the current status for obtaining claims data from ICBC's claims database. However for this research endeavor, the data was subjected to a significant amount of post-processing resulting in very useful and accurate claims data. Each auto insurance claim record was reviewed and important information was extracted and verified. In addition, since an auto insurance claim can be generated as a result of an event that should not be attributed to a road safety problem (i.e., an auto theft, vandalism or due to windshield damage), these non-collision related claims were removed from the sample. The process to obtain the claims and collision data for this research was quite involved and is described below, together with a figure to graphically illustrate the process.

1. First, all of the claims data was obtained from ICBC for the required locations (i.e., signalized intersections in the cities of Vancouver and Richmond).
2. Second, the data was screened to eliminate all non-collision related claims (i.e., auto theft, vandalism, windshield damage, etc.).

3. Third, the collision related claims were matched by intersection location and time of day to obtain the number of claim-based collisions. This matching process is necessary since one collision often involves more that one claim.
4. The fourth step involved obtaining copies of the police attended collision records for the specified locations from the two municipalities (i.e., copies of the MV104 collision report form).
5. Finally, the police attended collisions were matched against the claim-based collisions at each intersection. As expected, when these two data sources were compared, the matching process was considerably less than perfect. The collision data used for this research resulted from the summation of the following three outcomes:

Outcome 1: The collision frequency at each intersection includes the total number of matches between claim-based collisions and police attended collisions.

Outcome 2: The collision frequency at each intersection includes the non-matched, claims-based collisions. Many more claim-based collisions existed as compared to police reported collisions. There are many reasons for this difference. Some collisions are below the threshold level necessary for the police to report a collision (in BC, defined as $1000 property damage). Other collisions were reportable but were simply not reported by or to the police. In addition, occasional coding errors made by the police cause these incorrect collision records to be unusable.

Outcome 3: The collision frequency at each intersection included collisions that were reported by police but no claim records existed. This could occur if the vehicle was not insured by ICBC (out-of province vehicle) or was privately insured. However, this mismatch did not account for a large proportion of the total incidents.

The data process and outcomes are presented graphically in Figure 3.1.

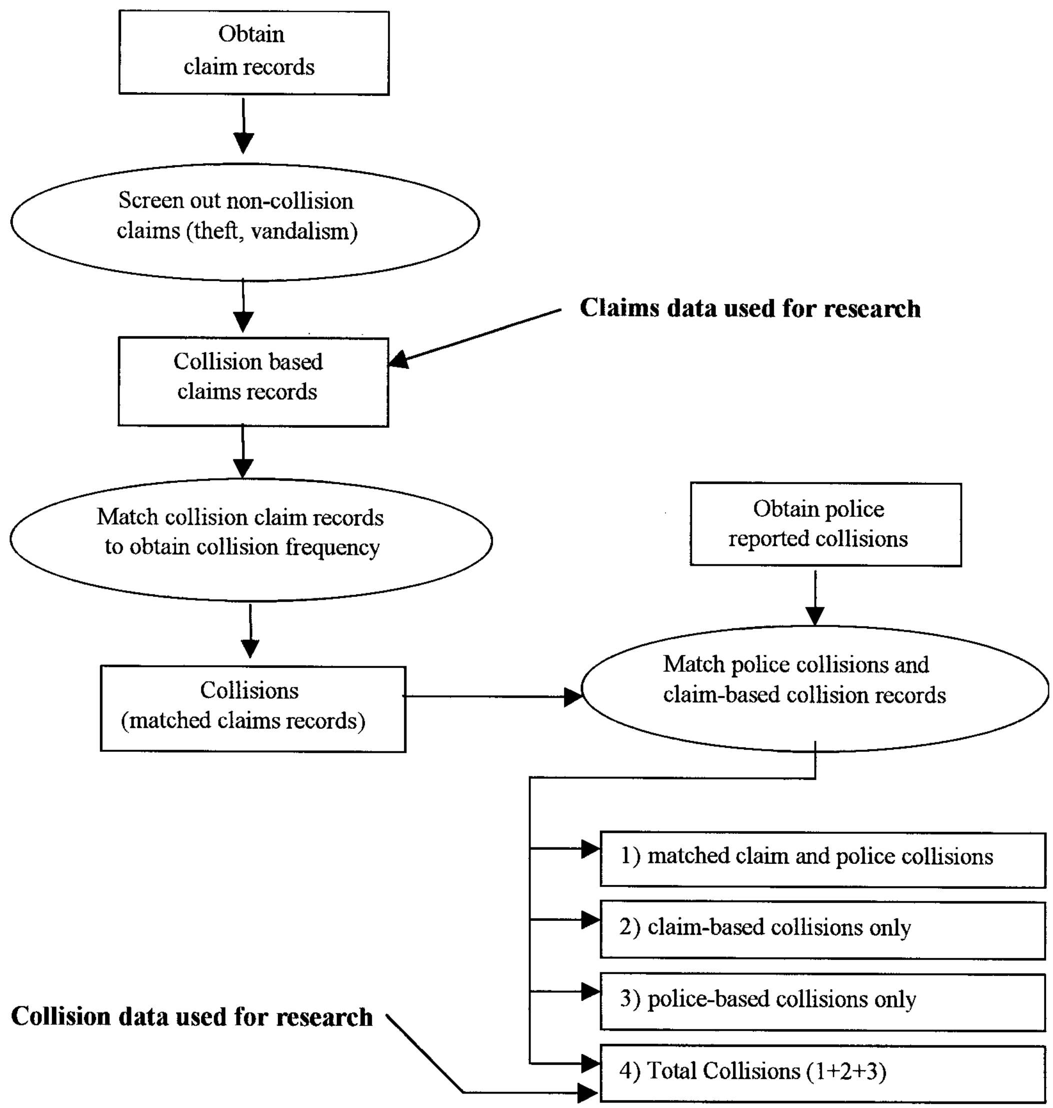

Figure 3.1: Illustration to Describe the Data Compilation Process

To conclude, it was determined that the claims-based collision data in addition to the police attended collisions provided a better estimate of the true number of collisions occurring at each intersection, and thus, was used for this research. It must also be emphasized that claims data is available in British Columbia due to the public nature of ICBC, thereby providing a unique opportunity for safety analysis and that the claims data is becoming more accessible. However, this claims data may not be available in many other jurisdictions.

3.2 Claims Data

The data used for this research project consisted of a listing of 108 intersections in the cities of Vancouver and Richmond BC. Associated with each intersection are the total number of claims, the total number of collisions (both the total collisions and injury collisions), and the traffic volumes on each of the intersection streets (the major and minor roadways).

The claims and collision data was obtained from ICBC and municipal police records, while the traffic volumes, given in the average annual daily traffic (AADT), were obtained from the Engineering Departments of each City. The time period for the claims and collision data included all incidents that occurred from January 1, 1995 to December 31, 1997. The traffic volume data represents the average daily traffic, averaged over the three years. Table 3.2 provides a statistical summary of the data used for this research.

Table 3.2: Statistical Summary of Auto Claims, Collision and Traffic Volume Data

Variable	Statistics			
	Minimum Value	Maximum Value	Mean Value	Standard Deviation
Major Road AADT	10,816	68,043	35,593	11,384
Minor Road AADT	4,607	39,616	20,239	8,222
Total Claims (3 years)	12	389	172.13	88.10
Total Collisions (3 years)	10	292	125.02	63.74
Injury Collisions (3 years)	7	147	53.14	29.16

The claim, collision and traffic volume data collected will be used to develop the claim and collision prediction models. These models will be used to compare the results produced from the claim records with the results from collision records, and thereby demonstrating the usefulness of claims records in road safety evaluation.

3.3 Modeling Road Safety

Models that have been developed to relate vehicle collisions and traffic volumes have been the focus of numerous studies. Alternatively, there have not been any studies undertaken to relate the frequency of auto insurance claims to traffic volume. The methodology used for modeling collisions is similar to that of claims and will use the generalized linear modeling approach (GLIM).

In general, there are two main approaches that can be used to model road safety. The first option is to use conventional linear regression, whereas the second option is to use a generalized linear modeling approach (GLIM). Conventional linear regression assumes a Normal distribution error structure whereas a generalized linear modeling approach (GLIM) assumes a non-Normal distribution error structure (usually Poisson or negative binomial). Historically, many researchers developed collision prediction models using conventional linear regression. However, several researchers (Jovanis and Chang, 1986), (Hauer et-al., 1988, Saccomanno and Buyco, 1988, Miaou and Lum, 1993) have shown that conventional linear regression models lack the distributional property to adequately describe collisions. This inadequacy is due to the random, discrete, non-negative, and typically sporadic nature that characterize the occurrence of a vehicle collision (these characteristics also describe an auto insurance claim). GLIM has the advantage of overcoming these shortcomings associated with conventional linear regression and recognizing these advantages, the GLIM approach will be utilized in this study.

The GLIM approach is based on the work of Hauer (Hauer, 1988) and Kulmala (Kulmala, 1995). Assuming that Y is a random variable that describes the number of auto insurance claims at an intersection in a specific time period, and y is the observation of this variable during a period of time. The mean of Y is Λ which can also be regarded as a random variable. Then for $\Lambda=\lambda$, Y is Poisson distributed, with parameter λ and the expected value is equal to the variance as shown in equations (3.1) and (3.2).

$$P(Y = y \mid \Lambda = \lambda) = \frac{\lambda^y e^{-\lambda}}{y!} \tag{3.1}$$

$$E(Y \mid \Lambda = \lambda) = \lambda; \quad Var(Y \mid \Lambda = \lambda) = \lambda \tag{3.2}$$

Since each site has its own regional characteristics with a unique mean collision (or claim) frequency Λ, Hauer (Hauer, 1988) has shown that for an imaginary group of sites with similar characteristics, Λ follows a gamma distribution (equation (3.3)). The gamma distribution has parameters κ and κ/μ, where κ is the shape parameter of the distribution and the mean and variance given in equation (3.4).

$$f_\Lambda(\lambda) = \frac{(\kappa/\mu)^\kappa \lambda^{\kappa-1} e^{-(\kappa/\mu)\lambda}}{\Gamma(\kappa)} \tag{3.3}$$

$$E(\Lambda) = \mu; \quad Var(\Lambda) = \frac{\mu^2}{\kappa} \tag{3.4}$$

Hauer (Hauer, 1988) and Kulmala (Kulmala, 1995) have also shown that the point probability function of Y, based on equations (3.3) and (3.4), is given by the negative binomial distribution (equation (3.5)) with an expected value and variance, shown below in equation (3.6). As shown in Equation (3.6), the variance of the observed number of auto insurance claims is generally larger than its expected value. The only exception is when $\kappa \to \infty$, in which case the variance equals the expected value which is identical to the Poisson distribution (Kulmala, 1995).

$$P(Y = y) = \frac{\Gamma(\kappa + y)}{\Gamma(\kappa) y!} \left(\frac{\kappa}{\kappa + \mu} \right)^\kappa \left(\frac{\mu}{\lambda + \mu} \right)^y \tag{3.5}$$

$$E(Y) = \mu; \quad Var(Y) = \mu + \frac{\mu^2}{\kappa} \tag{3.6}$$

The main difficulty associated with using the negative binomial distribution error structure is determining the shape parameter κ. There are several approaches to estimate the parameter κ of the negative binomial distribution. The macro library of the GLIM software (NAG (2), 1996) contains three methods: maximum likelihood, mean χ^2 and mean deviance. The method of maximum likelihood has been the most widely used (Hauer, 1988, Bonneson and McCoy, 1993, Maher and Summersgill, 1996). The statistical background of the three methods is given in Lawless (Lawless, 1987).

As described earlier, for the GLIM approach, the error structure is assumed to be Poisson or negative binomial. The main advantage of the Poisson error structure is the simplicity of the calculations (i.e., the mean and variance are equal). However, this advantage is also a limitation. It has been shown (Kulmala and Roine, 1988, Kulmala, 1995) that most collision data (and likely the claims data) is likely to be over-dispersed (i.e., the variance is greater than the mean) which indicates that the negative binomial distribution is usually the more realistic assumption.

There are three potential sources for over-dispersion in collision or claims data (Miaou and Lum, 1993). The first source of over-dispersion may be due to variables that have been omitted but which explain the occurrence of an incident. These variables include such factors as geometric road character (horizontal or vertical curve, lane widths, etc.), driver behavior, and environmental concerns that are not discernable from a collision or claim record. The second source for over-dispersion may be related to uncertainties in traffic volume data (obtained through the data collection process). Finally, the third source of over-dispersion in the data comes from the non-homogeneity of different roadway environments, which can explain why the safety performance is different during daylight or nighttime, or different between rainy and sunny days.

3.4 Developing the Claims Prediction Model

3.4.1 Model Structure

The model structure used in this study relates the frequency of auto insurance claims (or the frequency of collisions) to the product of traffic flows entering the intersection. In some cases, the **sum** of the traffic flows entering the intersection is used instead of the **product** of the traffic flows. However, it is has been shown (Hauer, 1988) that a model that utilizes the product of traffic flows provides a better representation of the relationships between collisions (or claims) and the traffic flows at intersections. In this model structure, claim frequency is a function of the product of traffic flows raised to a specific power (usually less than one). The model form is shown below in equation (3.7).

$$E(\Lambda) = a_{o} V_1^{a_1} V_2^{a_2} \tag{3.7}$$

where:	$E(\Lambda)$	= expected auto insurance claim frequency,
	V_1, V_2	= major / minor road traffic volume (AADT),
	a_{o}, a_1, a_2	= model parameters.

As described earlier, the occurrence of an collision (or claim) at an intersection is not only a function of the traffic flows entering the intersection, but also as a result of other characteristics at the intersection (geometric design, intersection type, environmental factors, and so on). Kulmala (Kulmala, 1995) and Maher (Maher, 1996) proposed to model these additional characteristics (variables) along with the traffic volumes as shown in equation (3.8). This model form is not used for this research on the use of claims data but is included for completeness.

$$E(\Lambda) = a_0 V_1^{a_1} \; V_2^{a_2} \; e^{\sum_{j=1}^{m} b_j x_j} \tag{3.8}$$

where:	x_j	= represents any of the m additional variables.
	b_j	= model parameters.

3.4.2 Model Development

The estimation of model parameters is based on a methodology proposed by Bonneson and McCoy (Bonneson and McCoy, 1993) and is used to determine whether a Poisson or negative binomial error structure should be used. First, the model parameters are estimated based on a Poisson error structure. Secondly, a dispersion parameter (σ_d) is calculated as shown is equation (3.9).

$$\sigma_d = \frac{Pearson\ \chi^2}{n-p} \tag{3.9}$$

where: n = the number of observations, and

p = the number of model parameters.

The *Pearson* χ^2 is used to assess the significance of GLIM models (described further in a subsequent section) and is defined below in equation (3.10).

$$Pearson\ \chi^2 = \sum_{i=1}^{n} \frac{[y_i - E(\Lambda_i)]^2}{Var(y_i)} \tag{3.10}$$

where: y_i = observed number of claims at an intersection

$E(\Lambda_i)$ = predicted number of claims obtained from model,

$Var(y_i)$ = the variance of the observed claims.

If σ_d is approximately equal to 1.0, then the assumed error structure approximately fits the Poisson distribution. If σ_d is greater than 1.0, then the data has greater dispersion than is explained by the Poisson distribution, and a further analysis using a negative binomial error structure is required. In this case, the parameters are estimated using an iterative process based on the maximum likelihood estimate (Hauer, 1988). This iterative process has been added to the macro library of the GLIM software (NAG (2), 1996).

3.4.3 Testing the Significance of GLIM Models

Several measures can be used to assess the significance of GLIM models. Two commonly used measures include using the Scaled Deviance (SD) and the *Pearson* χ^2 statistic. The SD is defined as the likelihood test ratios, measuring the difference between the log likelihood of the studies model and the saturated model (Kulmala, 1995). The specific formulation of SD for the Poisson distribution and the negative binomial distribution are shown in equation (3.11) and (3.12) respectively.

$$SD = 2\sum_{i=1}^{n} y_i \ln\left(\frac{y_i}{E(\Lambda_i)}\right) \qquad (3.11)$$

$$SD = 2\sum_{i=1}^{n}\left[y_i \ln\left(\frac{y_i}{E(\Lambda_i)}\right) - (y_i+\kappa)\ln\left(\frac{y_i+\kappa}{E(\Lambda_i)+\kappa}\right)\right] \qquad (3.12)$$

The scaled deviance (SD) is asymptotically χ^2 distributed with *n-p-1* degrees of freedom and therefore for a well-fitted model, the expected value of the SD will be approximately equal to the number of degrees of freedom (Maycock and Hall, 1984).

The *Pearson* χ^2 statistic is another measure to assess the significance of a GLIM model and was defined in Section 3.4.2 (Model Development) and shown again below in equation (3.13). The *Pearson* χ^2 statistic follows the χ^2 distribution with *n-p-1* degrees of freedom and therefore for a well-fitted model, the expected value of the *Pearson* χ^2 should be approximately equal to the number of degrees of freedom.

$$Pearson\,\chi^2 = \sum_{i=1}^{n}\frac{[y_i - E(\Lambda_i)]^2}{Var(y_i)} \qquad (3.13)$$

In addition to the scaled deviance (SD) and the *Pearson* χ^2 statistic, there are several useful subjective, graphical measures that can be used to test a model's goodness of fit. The first method is to simply plot the predicted collision (or claim) frequency versus the observed collision (or claim) frequency. A well-fitted model should have all points clustered around a 45° line.

A second graphical technique is to plot the average of squared residuals versus the predicted collision (or claim) frequency. For a well fitted model, all points should be around the variance function line as defined in equation (3.2) and (3.4) for the Poisson and negative binomial distributions respectively.

The third subjective graphical method is to calculate the Pearson Residual (*PR*) (or the Prediction Ratio) and plot it against the predicted collision (or claim) frequency. *PR* is defined as the difference between the predicted and observed collision (or claim) frequency divided by the standard deviation (Bonneson and McCoy, 1997). The formulation for the Pearson Residual (*PR*) is shown below in equation (3.14). For a well-fitted model, the Pearson Residuals should be clustered around zero over the range of $E(\Lambda)$ (Bonneson and McCoy, 1997).

$$PR_i = \frac{E(\Lambda_i) - y_i}{\sqrt{Var(y_i)}} \tag{3.14}$$

where: $E(\Lambda_i)$ = predicted number of claims from claim model,

y_i = observed number of claims at an intersection,

$\sqrt{Var(y_i)}$ = the standard deviation of the observed claims.

Finally, the statistical significance of the model variables can be assessed using the t-ratio test. The t-ratio is the ratio between the estimated GLIM parameter coefficient and it's standard error. For a significant variable at the 95% level of confidence, the t-ratio should be greater than 1.96.

3.5 Results of the GLIM Modeling

A total of three prediction models were developed from the claim and collision data that were obtained. The models developed are assumed to follow the negative binomial distribution, included within the GLIM software package through a macro designed by NAG (NAG (2), 1996). The objectives for each of the three models are defined below:

Model 1: Predicts the total number of claims in 3 years at an urban intersection based on major and minor road volumes.

Model 2: Predicts the total number of collisions in 3 years at an urban intersection based on major and minor road volumes.

Model 3: Predicts the total number of injury collisions in 3 years at an urban intersection based on major and minor road volumes.

Table 3.3 presents the three prediction models developed, detailing the model parameters. Each model predicts the 3-year frequency of claims or collisions, based on the average daily traffic in thousand vehicles per day.

Table 3.3: Developed Claim and Collision Prediction Models

Model Formulation	t-ratio		κ	Pearson χ^2 (χ^2 test)	S.D. (DoF)
MODEL 1: Total Claims Model: $Claims/3yrs = 2.7429 \times \left(\frac{AADT_{maj\ \mathrm{rd}}}{1000}\right)^{0.8256} \times \left(\frac{AADT_{\mathrm{mnr\ rd}}}{1000}\right)^{0.4028}$	A_o A_1 A_2	2.3 6.8 4.3	5.36	101 (129)	113 (105)
MODEL 2: Total Collision Model: $Collisions/3yrs = 2.1366 \times \left(\frac{AADT_{maj\ \mathrm{rd}}}{1000}\right)^{0.8256} \times \left(\frac{AADT_{\mathrm{mnr\ rd}}}{1000}\right)^{0.3793}$	A_o A_1 A_2	1.7 6.8 4.1	5.55	105 (129)	109 (105)
MODEL 3: Injury Collision Model: $Inj.\ \mathrm{Collisions}/3yrs = 0.6098 \times \left(\frac{AADT_{maj\ \mathrm{rd}}}{1000}\right)^{0.9435} \times \left(\frac{AADT_{\mathrm{nrn\ rd}}}{1000}\right)^{0.3695}$	A_o A_1 A_2	1.7 7.7 4.0	6.03	107 (129)	103 (105)

As described in Section 3.4.3, several measures are used to define the goodness of fit for each model. These measures include the t-ratio test, the κ value, the *Pearson* χ^2 statistic, the χ^2 value, and the scaled deviance (SD). These measures indicate that the three prediction models have a relatively good fit and the value that is calculated for the t-ratios for all independent variables are significant.

Three figures are also used to demonstrate the goodness of fit for each model. The first figure for each model plots the observed frequency versus the predicted frequency (either claims or collisions) at each intersection. The second figure depicts the relationship between the variance of the observed frequency and the average squared residuals. Each point represents the average of the predicted frequency for a sequenced group of intersections. The third figure shows the relationship between the predicted frequency and the Pearson residual. The following three pages show the three figures associated with each prediction model developed.

As evidenced by the figures on the following three pages, reasonably good fit was achieved for each model. The figures that plot the observed versus the predicted frequency (Figures 3.2, 3.5, and 3.8) show that the points fall close to the 45° line which indicate well-fitted models. The figures showing the squared residuals (averaged for 10 sequential intersections) versus the predicted frequency (Figures 3.3, 3.6, and 3.9) also indicate well-fitted models. Finally, the graphs showing the Pearson residual versus the predicted frequency (Figures 3.4, 3.7, and 3.10) illustrates that the residuals are clustered around zero over the range of predicted values indicating valid models.

Overall, each of the three prediction models is considered to be valid and fit the observed collision or claim data very well.

3.6 Applications of the Claim Prediction Model

Given that the models have been shown to be valid, two applications using the developed claim prediction model will be presented. The purpose is to demonstrate the usefulness of the claims prediction model in road safety analysis and evaluation. The first application will show how the claim prediction model can be used to identify problematic locations or locations with a higher than expected number of auto insurance claims. The second application demonstrates how the results from the claim prediction model can be used to prioritize or rank the problematic locations identified.

3.6.1 Location Specific Prediction: The Empirical Bayes Refinement

Before demonstrating the usefulness of the claim prediction model in identifying hazardous locations, it is important to understand how to improve the reliability of location specific predictions. Due to the randomness that is inherent in the occurrence of a collision (and therefore a claim), it is important to deploy statistical techniques that can effectively account for randomness when identifying problematic locations. A statistical technique known as the Empirical Bayes (EB) refinement (as described below) can be used to identify problematic locations.

In general, two types of clues are available to determine the safety performance of a location: its traffic / road characteristics, and its historical collision frequency (or claim frequency) (Hauer, 1992, Brüde and Larsson, 1988). The Empirical Bayes (EB) approach makes use of both of these clues. For this study the EB approach is used to refine the estimate of the expected number of claims at a location by combining the observed number of claims at the location with the predicted number of claims obtained from the GLIM model. This will yield a more accurate, location-specific safety estimate.

The EB estimate will provide the expected number of claims for any intersection and can be calculated by using equation (3.15) (Hauer, 1992).

$$EB_{safety\ estimate} = \alpha \times E(\Lambda) + (1-\alpha) \times count \tag{3.15}$$

and,

$$\alpha = \frac{1}{1 + \frac{Var(E(\Lambda))}{E(\Lambda)}} \tag{3.16}$$

. where: *count* = observed number of claims,

E(Λ) = predicted claims, estimated by the GLIM model, and

Var(E(Λ)) = variance of the GLIM estimate.

Since $Var(E(\Lambda)) = \frac{E(\Lambda)^2}{\kappa}$, equation (3.15) is rearranged to yield the following:

$$EB_{safety\ estimate} = \left(\frac{\kappa}{\kappa + E(\Lambda)}\right) E(\Lambda) + \left(\frac{E(\Lambda)}{\kappa + E(\Lambda)}\right)(count) \tag{3.17}$$

The variance of the *EB* estimate is calculated using the following equation:

$$Var(EB_{safety\ estimate}) = \left(\frac{E(\Lambda)}{\kappa + E(\Lambda)}\right)^2 (\kappa) + \left(\frac{E(\Lambda)}{\kappa + E(\Lambda)}\right)(count) \tag{3.18}$$

As shown in the formulation of equation 3.17, the EB safety estimate lies between the observed number of claims and the predicted number of claims. Thus, the EB estimate uses both the location specific claim frequency (observed) and the predicted value (from the GLIM model) to refine the estimate.

The κ parameter also is an important factor in the calculation of the EB estimate. With a high value for κ, the variance of the predicted frequency is low (equation (3.4)) and therefore there is little uncertainty as the EB estimate is close to the predicted (GLIM) estimate. Conversely, when the value of κ is low, the variance of the predicted frequency is high, creating great uncertainty with the GLIM model as the EB estimate becomes close to the observed frequency. The impact of the κ parameter and the EB estimate is shown in Figure 3.11.

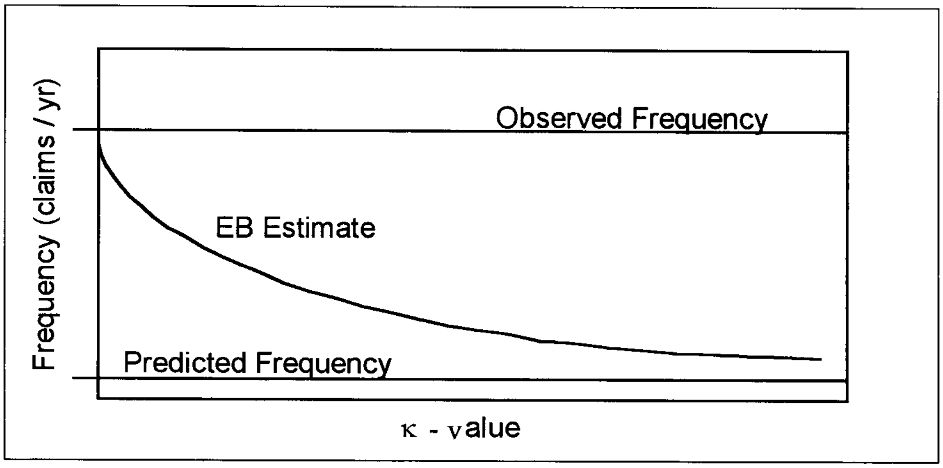

Figure 3.11: Empirical Bayes Estimate for Different κ Values

It has also been shown that the EB estimate significantly reduces the regression to the mean effects that are inherent in observed collision (and claim) counts (Brüde and Larsson, 1988). Regression to the mean is a statistical phenomenon in which a randomly large number of events (i.e., incidents) during a 'before' period is normally followed by a reduced number of events during an 'after' period, even if no changes have occurred from the before to the after periods. The converse also applies: a randomly small number of events in a before period is normally followed by an increase in the frequency events in an after period.

3.6.2 Identifying Hazardous Locations

For this research, a problematic location is defined as any location that exhibits a significantly higher number of auto insurance claims as compared to a specific normal value. It has been stated that the EB refinement method should be used to improve the location specific prediction and thus, is used to identify hazardous locations. The EB refinement method is used to identify problem sites according to the following four-step process (Higle and Witkowski, 1988; Bélanger, 1994).

1. Estimate the predicted number of claims and its variance for the intersection, using the appropriate GLIM model. This follows a gamma distribution (the prior distribution) with parameters α and β, where:

$$\beta = \frac{E(\Lambda)}{Var(\Lambda)} = \frac{\kappa}{E(\Lambda)} \text{ and } \alpha = \beta \cdot E(\Lambda) = \kappa \tag{3.19}$$

2. Determine the appropriate point of comparison based on the mean and variance values obtained in step (1). Usually the 50th percentile (P_{50}) or the mean $E(\Lambda)$ is used as a point of comparison. P_{50} is calculated such that:

$$\int_0^{P_{50}} \frac{(\kappa / E(\Lambda))^{\kappa} \cdot \lambda^{\kappa-1} \cdot e^{-(\kappa / E(\Lambda))\lambda}}{\Gamma(\kappa)} d\lambda = 0.5 \tag{3.20}$$

3. Calculate the EB safety estimate and its variance from Equations (3.17) and (3.18). This is also a gamma distribution (the posterior distribution) with parameters α_1 and β_1:

$$\beta_1 = \frac{EB}{Var(EB)} = \frac{\kappa}{E(\Lambda)} + 1 \quad \text{and} \quad \alpha_1 = \beta_1 \cdot EB = \kappa + count \tag{3.21}$$

Then, the probability density function of the posterior distribution is:

$$f_{EB}(\lambda) = \frac{(\kappa / E(\Lambda) + 1)^{(\kappa + count)} \lambda^{\kappa + count - 1} e^{-(\kappa / E(\Lambda) + 1)\lambda}}{\Gamma(\kappa + count)} \tag{3.22}$$

4. Identify the location as claim-prone if there is a significant probability that the intersection's safety estimate exceeds the P_{50} value. Thus, the location is identified as claim prone based on equation 3.23. In equation (3.23), δ represents the confidence level that is desired (usually selected at 0.95).

$$\left[1 - \int_0^{P_{50}} \frac{(\kappa / E(\Lambda) + 1)^{(\kappa + count)} \lambda^{\kappa + count - 1} e^{-(\kappa / E(\Lambda) + 1)\lambda}}{\Gamma(\kappa + count)} d\lambda \right] \geq \delta \tag{3.23}$$

Figure 3.12 illustrates the process of identifying hazardous locations in a graphical form. The prior distribution represents what is normal, obtained from the predicted frequency (i.e., from the GLIM model). The posterior distribution represents what is actually occurring, obtained from the observed EB frequency estimate. The shaded area represents the probability that the observed EB frequency estimate is less than the mean frequency when compared to what is normally expected.

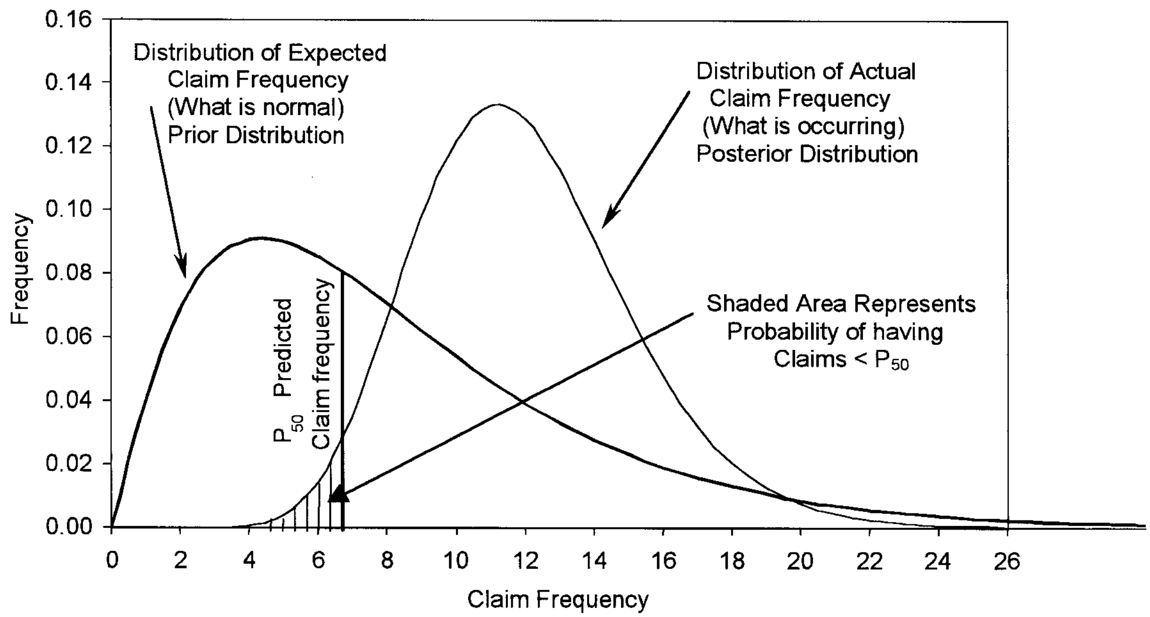

Figure 3.12: Identification of Hazardous Locations

At this point, an example is provided to demonstrate the calculation of the EB estimate, followed by the calculation to determine whether the location is considered to be prone to claims. Consider the signalized intersection of Kingsway Avenue and Knight Street in Vancouver that has the following characteristics:

Major Road AADT:	39,083 vehicles / day
Minor Road AADT:	27,890 vehicles / day
Observed Claims:	228 claims / 3 years

Using the claims prediction models shown in Table 3.3, the normal value that would be expected at the intersection can be calculated to be 216.16 claims per three years. The parameters of the prior gamma distribution (α_1 and β_1) can also be calculated knowing that the κ value for the claim prediction model is 5.36.

$$predicted\ claims\ /\ 3yrs = 2.7429 \times \left(\frac{39{,}083}{1000}\right)^{0.8256} \times \left(\frac{27{,}890}{1000}\right)^{0.4028} = 216.16\, claims\ /\ 3yrs$$

$$\beta_1 = \frac{\mathrm{E}(\Lambda)}{\mathrm{Var}(\Lambda)} = \frac{\kappa}{\mathrm{E}(\Lambda)} = \frac{5.36}{216.16} = 0.025$$

$$\alpha_1 = \beta_1 \cdot \mathrm{E}(\Lambda) =).025 \mathrm{x} (216.16) = \kappa = 5.36$$

The Empirical Bayes (EB) safety estimate and the variance of the estimate are then calculated by using equation (3.17) and (3.18). For this example, the observed number of claims is reduced from 228 to 227.71, representing a slight correction for regression to the mean phenomenon and the variance of the *EB* estimate is calculated to be 222.21 (claims / 3yrs.)^2.

$$EB_{safety\ estimate} = \left(\frac{5.36}{5.36 + 216.16}\right) 216.16 + \left(\frac{216.16}{5.36 + 216.16}\right)(228) = 227.71\, claims\ /\ 3yrs$$

$$Var(EB_{safety\ estimate}) = \left(\frac{216.16}{5.36 + 216.16}\right)^2 (5.36) + \left(\frac{216.16}{216.16 + 5.36}\right)^2 (228) = 222.21 (claims\ /\ 3yrs)^2$$

The next step is to determine the appropriate point for comparison on the prior distribution based on the predicted mean and variance values. The 50th percentile is used as a point of comparison and is calculated using equation (3.20). Solving the integral to equal 0.5, the P50 value is calculated to be 202.87 claims per three years.

$$\int_0^{P_{50}} \frac{(5.36/216.16)^{5.36} \cdot \lambda^{5.36-1} \cdot e^{-(5.36/216.16)\lambda}}{\Gamma(5.36)} d\lambda = 0.5$$

P_{50} = 202.87 claims / year

Knowing the EB estimate and its variance (227.71 and 222.21 respectively), the parameters of the posterior distribution can be determined (α_2 and β_2).

$$\beta_2 = \frac{\text{EB}}{\text{Var(EB)}} = \frac{\kappa}{\text{E}(\Lambda)} + 1 = \frac{5.36}{216.16} + 1 = 1.025$$

$$\alpha_2 = \beta_2 \cdot \text{EB} = \kappa + \text{count} = 5.36 + 228 = 233.36$$

Using the parameters of the posterior distribution and the P_{50} value from the prior distribution as a basis for comparison, the intersection can be evaluated to determine if it is prone to claims. The intersection is considered hazardous if there is significant probability that the intersections safety estimate exceeds the P_{50} value.

Thus, using equation (3.23), the intersection is considered prone to claims if the confidence level (δ) exceeds 0.95.

$$\delta = 1 - \int_0^{202.87} \frac{(5.36/216.16+1)^{(5.36+228)} \lambda^{(5.36+228-1)} e^{-(5.36/216.16+1)\lambda}}{\Gamma(5.36+228)} d\lambda$$

$\delta = 0.9563$

This illustrative example indicates that there is a significant probability (95.6%) of exceeding the P_{50} value and that the intersection can be considered prone to claims. Refer to Figure 3.12 to see a graphical representation of this process.

This technique to identify claim prone locations was applied to all 108 intersections used in this study. Using the P_{50} value as a reference point for the comparison between the normal (expected) claim frequency and the actual claim frequency and a value of $\delta > 0.95$, there were 40 locations that were identified as being claim prone. The results are summarized in Table 3.4. Fewer hazardous locations would be identified with a higher reference point (i.e., P_{75}), and/or a higher confidence level (i.e., $\delta > 0.99$).

Table 3.4: Summary of Hazardous Locations

Location Description				Volume (1000s)		Claim Frequency			Area δ
No.	Major Road	**Minor Road**	**ID**	**Major**	**Minor**	**Observed**	**Predicted**	**EB Refined**	CPL[1] δ>0.95
1	No. 2 Rd	Blundell	**6**	24.055	11.767	175	102.28	171.38	1.0000
2	Cambie	No. 5	**17**	12.511	12.043	120	60.18	115.11	1.0000
3	Garden City	Blundell	**21**	14.419	11.647	154	66.76	147.52	1.0000
4	Westminster	No. 3	**25**	29.815	27.227	188	171.20	187.49	0.9807
5	Commercial	1st Ave	**29**	45.895	22.546	272	226.55	270.95	0.9999
6	Commercial	Broadway	**30**	43.831	23.776	265	222.83	264.01	0.9999
7	Victoria Dr.	49th Ave	**32**	25.362	24.26	238	143.00	234.57	1.0000
8	41st Ave	Granville	**34**	49.084	25.007	287	249.68	286.22	0.9995
9	41st Ave	Oak	**35**	48.732	31.854	373	273.61	371.09	1.0000
10	41st Ave	Knight	**38**	39.462	35.275	262	239.51	261.51	0.9916
11	41st Ave	Victoria	**39**	36.082	29.832	234	207.92	233.35	0.9961
12	49th Ave	Fraser	**40**	22.585	21.685	272	124.20	265.89	1.0000
13	49th Ave	Main	**41**	23.989	20.689	180	128.09	177.92	1.0000
14	49th Ave	Granville	**44**	37.572	15.807	209	166.46	207.67	1.0000
15	1st Ave.	Renfrew	**47**	53.783	18.795	259	240.00	258.59	0.9851
16	4th	Arbutus	**50**	24.704	8.232	112	90.54	110.80	0.9968
17	12th	Rupert	**51**	52.179	21.924	373	249.05	370.39	1.0000
18	12th	Cambie	**58**	35.855	28.499	259	203.07	257.56	1.0000
19	12th	Granville	**60**	26.311	22.170	164	142.15	163.21	0.9940
20	Boundary	Grandview	**61**	46.120	36.093	330	274.94	328.95	1.0000
21	Boundary	Kingsway	**62**	43.950	33.623	326	256.78	324.59	1.0000
22	Broadway	Macdonald	**71**	17.743	13.653	138	84.46	134.81	1.0000
23	Cambie	41st	**76**	33.703	29.603	389	195.93	383.86	1.0000
24	Cambie	Marine	**77**	44.680	19.850	343	210.51	339.71	1.0000
25	Granville	16th	**79**	29.120	20.890	232	150.91	229.22	1.0000
26	Granville	70th	**82**	41.301	13.930	275	171.05	271.84	1.0000
27	Hastings	Boundary	**83**	34.635	14.172	217	148.94	214.64	1.0000
28	Hastings	Nanaimo	**85**	40.101	16.032	209	176.66	208.05	0.9993
29	Hastings	Clark	**86**	37.297	16.456	198	168.16	197.08	0.9988
30	Hastings	Main	**87**	22.055	11.837	138	95.43	135.74	1.0000
31	Kingsway	Joyce	**88**	45.324	13.843	278	184.23	275.35	1.0000
32	Kingsway	Victoria	**91**	49.249	24.275	357	247.39	354.68	1.0000
33	Kingsway	Knight	**92**	39.083	27.890	228	216.16	227.71	0.9563
34	Knight	49th	**95**	44.754	25.594	312	233.52	310.24	1.0000
35	Knight	57th	**96**	40.73	14.049	242	169.68	239.79	1.0000
36	Main	Terminal	**97**	46.892	33.865	315	271.67	314.16	0.9998
37	Main	Marine	**100**	47.404	13.020	314	186.52	310.44	1.0000
38	Marine Dr.	Fraser	**103**	47.504	7.790	326	151.92	320.07	1.0000
39	Marine Dr.	Oak	**104**	45.701	7.420	193	144.29	191.26	1.0000
40	Oak	King Edward	**105**	23.166	22.582	216	128.92	212.53	1.0000
40	**TOTAL Number of Hazardous Locations**								

1. CPL = Claim Prone Location. CPL identified when δ > 0.95 based on P_{50} point of comparison.

3.6.3 Ranking Hazardous Locations

Once sites are identified as problematic, it is important for road authorities to rank the locations in terms of priority for scheduled treatment. Ranking problematic sites enables road authorities to establish an effective safety program, ensuring the efficient use of limited funding available for road safety, thus representing a **cost-effective** objective. A road authority also has an obligation to ensure that all locations have approximately an equal level of risk, such that the probability of becoming involved in an incident is the same at all locations, regardless of the frequency of incidents, thus representing a **risk-minimization** objective. The two techniques, described by Sayed and Rodriguez (Sayed and Rodiguez, 1998), reflect different priority objectives for a road authority to consider.

The first ranking criterion is to calculate the **ratio** between the EB estimate and the predicted frequency as obtained from the GLIM model (the risk-minimization objective). The ratio represents the level of deviation that the intersection is away from a "normal" safety performance value. The higher the ratio, the more hazardous the location and conversely, the lower the ratio, the less hazardous the location. Thus, each problematic location can be ranked in descending order according to this ratio. The ratio of EB estimate to the predicted value was calculated for the 40 locations that were identified as prone to claims and the results are summarized in Table 3.5.

The second criterion, the cost-effectiveness objective, is to calculate the **difference** between the EB estimate and the predicted frequency (from the GLIM model) for each hazardous location. The difference between these two values is an effective indicator of the expected safety benefits measured by the potential reduction in claim frequency. In addition, this difference can be useful in estimating the pre-implementation safety benefits of a road improvement. The difference between the EB estimate and the predicted value was calculated for the 40 locations that were identified as claim-prone and the results are also summarized in Table 3.5.

Table 3.5: Ranking Hazardous Locations based on Claims Data

Ref.	Intersection		Claim Frequency			Criteria		Rank		Rank
ID	Major Road	Minor Road	Observed	Predicted	EB Refine	EB – Pred	EB / Pred	EB – Pred	EB / Pred	Difference
6	No. 2 Rd.	Blundell	175	102.28	171.38	69.101	1.676	17	6	11
17	Cambie	No. 5	120	60.18	115.11	54.931	1.913	20	5	15
21	Garden City	Blundell	154	66.76	147.52	80.763	2.210	13	1	12
25	Westminster	No. 3	188	171.20	187.49	16.286	1.095	39	37	2
29	Commercial	1st Ave	272	226.55	270.95	44.396	1.196	26	29	3
30	Commercial	Broadway	265	222.83	264.01	41.184	1.185	29	30	1
32	Victoria Dr.	49th Ave	238	143.00	234.57	91.571	1.640	10	9	1
34	41st Ave	Granville	287	249.68	286.22	36.537	1.146	31	35	4
35	41st Ave	Oak	373	273.61	371.09	97.478	1.356	9	21	12
38	41st Ave	Knight	262	239.51	261.51	21.995	1.092	35	38	3
39	41st Ave	Victoria	234	207.92	233.35	25.421	1.122	34	36	2
40	49th Ave	Fraser	272	124.20	265.89	141.689	2.141	3	2	1
41	49th Ave	Main	180	128.09	177.92	49.825	1.389	24	20	4
44	49th Ave	Granville	209	166.46	207.67	41.214	1.248	28	26	2
47	1st Ave.	Renfrew	259	240.00	258.59	18.587	1.077	38	39	1
50	4th	Arbutus	112	90.54	110.80	20.262	1.224	37	27	10
51	12th	Rupert	373	249.05	370.39	121.338	1.487	6	15	9
58	12th	Cambie	259	203.07	257.56	54.493	1.268	21	24	3
60	12th	Granville	164	142.15	163.21	21.058	1.148	36	34	2
61	Boundary	Grandview	330	274.94	328.95	54.006	1.196	22	28	6
62	Boundary	Kingsway	326	256.78	324.59	67.807	1.264	18	25	7
71	Broadway	Macdonald	138	84.46	134.81	50.343	1.596	23	11	12
76	Cambie	41st	389	195.93	383.86	187.932	1.959	1	4	3
77	Cambie	Marine	343	210.51	339.71	129.201	1.614	4	10	6
79	Granville	16th	232	150.91	229.22	78.313	1.519	14	13	1
82	Granville	70th	275	171.05	271.84	100.793	1.589	8	12	4
83	Hastings	Boundary	217	148.94	214.64	65.693	1.441	19	16	3
85	Hastings	Nanaimo	209	176.66	208.05	31.389	1.178	32	31	1
86	Hastings	Clark	198	168.16	197.08	28.923	1.172	33	32	1
87	Hastings	Main	138	95.43	135.74	40.303	1.422	30	18	12
88	Kingsway	Joyce	278	184.23	275.35	91.122	1.495	11	14	3
91	Kingsway	Victoria	357	247.39	354.68	107.283	1.434	7	17	10
92	Kingsway	Knight	228	216.16	227.71	11.554	1.053	40	40	0
95	Knight	49th	312	233.52	310.24	76.718	1.329	15	22	7
96	Knight	57th	242	169.68	239.79	70.111	1.413	16	19	3
97	Main	Terminal	315	271.67	314.16	42.489	1.156	27	33	6
100	Main	Marine	314	186.52	310.44	123.923	1.664	5	7	2
103	Marine Dr.	Fraser	326	151.92	320.07	168.148	2.107	2	3	1
104	Marine Dr.	Oak	193	144.29	191.26	46.966	1.325	25	23	2
105	Oak	King Edward	216	128.92	212.53	83.606	1.649	12	8	4

The results of this comparative analysis are presented graphically in a series of figures. Each figure shows the agreement in the ranking between claims, total collisions and injury collisions, comparing the EB estimate and the predicted value for both ranking techniques (difference and ratio). The figures shown on the following page include:

Figure 3.14: Agreement (EB – Predicted): Claims vs. Collisions
Figure 3.15: Agreement (EB – Predicted): Injury Collisions vs. Claims
Figure 3.16: Agreement (EB – Predicted): Injury Collisions vs. Collisions
Figure 3.17: Agreement (EB / Predicted): Claims vs. Collision
Figure 3.18: Agreement (EB / Predicted): Injury Collisions vs. Claims
Figure 3.19: Agreement (EB / Predicted): Injury Collisions vs. Collisions

The level of agreement between the two rankings methods for the claims versus total collisions is considered very good (Figures 3.14 and 3.17). The level of agreement is quite good for the {EB / Predicted} ranking for the injury collisions versus claims and for injury collisions versus total collisions (Figures 3.18 and 3.19). However, the level of agreement for the {EB – Predicted} ranking for the injury collisions versus claims and for injury collisions versus total collisions is not very good (Figures 3.15 and 3.16).

In addition to these ranking methodologies, there may be numerous other ranking criteria that can be used by relating both a ratio and a difference between observed and normal frequencies. These methods include ranking the observed to predicted claim frequency, the observed to the EB estimated claim frequency and so on. In all these cases, a similar methodology as that presented above can be used (i.e., ranking according to the difference and the ratio). There is a lack of research concerning the ranking criteria when using prediction models and thus, there may be an opportunity to expand the knowledge by undertaking future research.

3.7 Summary and Conclusions

This chapter has presented results on the use of auto insurance claims data in monitoring and evaluating road safety. The main research objective was to investigate a new approach to evaluate road safety by developing and applying a Claim Prediction Model. The claim prediction model has been developed based on auto insurance claim data available through the Insurance Corporation of British Columbia (ICBC). The motivation for this research was to address problems associated with the motor vehicle collision data in the province. The goal was to determine if the claims data could be used in engineering diagnosis of road safety and whether the claims data could be used in addition to or in place of collision data.

The data used for this research was obtained from ICBC as well as from the local road authorities, and include data for 108 urban, signalized intersections located in the lower mainland area of British Columbia. This data includes the auto insurance claims data, collision data (total and injury collisions), and the traffic volume data. This data was used to develop three prediction models; one to predict the number of claims, the second model to predict the total number of collisions and the third model that predicts the number of injury collisions. All three models provide the prediction based on major and minor traffic volumes entering the intersection. The generalized liner modeling approach (GLIM) was used to develop the models, as it has been shown to overcome shortcoming associated with conventional linear regression.

The significance of the GLIM models was evaluated in many ways. These measures include the scaled deviance (SD), the χ^2 value, the *Pearson* χ^2 statistic, and the t-ratio test. All three models have a relatively good fit and the value calculated for the t-ratios for all independent variables are significant. Three graphical techniques were also presented to demonstrate the goodness of fit of the models. Overall, each of the three prediction models is considered to be valid and fit the observed data very well.

Two applications for the claim prediction model were provided to demonstrate its usefulness in road safety engineering and analysis. The first application was the identification of problem locations and the second application was the ranking of these problem locations. The Empirical Bayes refinement approach (EB) was used to improve the reliability of location specific predictions thereby improving the application of the claim prediction model. A four-step process was used to identify problem sites, including a numerical example. The process identified 40 locations from the list of 108 intersections, being prone to auto-insurance claims.

In the second application, the ranking of problem locations, two ranking criteria were suggested to satisfy different priority objectives. The first objective attempts to identify locations where there is a large difference between the EB estimate and the predicted (normal) frequency. The second objective attempts to ensure that the risk at all locations is similar, by calculating the ratio of the EB estimate to the predicted (normal) value. The two ranking techniques were compared and offered somewhat similar results, although the differences were expected given the different objectives. The rankings produced by the claims data was then compared to the results produced by the collision information (both total collisions and injury collisions). The level of agreement between the rankings was considered very good for the relationship between claims versus total collisions.

Overall, the results produced by the claims data appear to be very encouraging for use in evaluating road safety. The results suggest that claims data may be used in place of the degrading police reported collision data. It has been shown that claims data can be used to evaluate road safety performance and that claims can be applied in a similar manner as collision records. It should be stressed however, that the claims data used for this analysis was subjected to considerable quality control and similar data may not be readily available within the claims database at ICBC. ICBC is continuing with their recent efforts to make reliable claims data more readily available. Once this data is available, it should be used for road safety evaluations.

4.0 DEVELOPMENT OF A ROAD SAFETY RISK INDEX

Several problems associated with the collision data were discussed in the introductory chapters of this thesis. To avoid these problems, it was believed that a subjective evaluation technique could be developed that did not rely on collision statistics, and which could be used to identify and diagnose problematic areas. Reducing a dependency on collision records seems prudent at this point in time, given the current status of collision reporting practices within many jurisdictions, including the province of British Columbia.

This chapter describes the development and application of a risk index to be used for road safety evaluation. The risk index is developed as a driver-based, subjective assessment of the potential road safety risks for in-service roadways. The chapter includes a short introduction to the topic, a review of literature related to the topic, the objectives of the risk index, the methodology that has been developed, a demonstration of the risk index, and some comparative results to test the validity of the risk index.

4.1 Background and Literature Review

4.1.1 Background

The main objective of developing a road safety risk index is to produce a technique to support road safety analysis, and a technique that does not rely on deteriorating collision data. Another reason for developing the subjective and driver-based evaluation of road safety risk is that there are important contributing factors that often cannot be extracted from a review of the collision statistics. These important factors can be described as the "human-factor" component of road safety and relate to the limitations of the road user in terms of operating, navigating, and controlling a vehicle within a road environment (Dewar, 1993). A driver-based, subjective evaluation technique can be developed to include the elements that are associated with human-factors as they impact road safety performance.

The development of a driver-based, subjective evaluation technique can also assist in the formulation of planned road improvements or countermeasures. The process of formulating a road safety risk index involves a trained road safety team driving the roadway to assess the road safety risks. As such, it becomes convenient to diagnose potential problems at hazardous locations and to propose possible improvements to the roadway. It should be noted that traditional road safety evaluations (those that utilize collision data) often require a site visit to determine or verify the problems and recommend specific solutions.

4.1.2 Literature Review

In reviewing the relevant literature, several sources describe different efforts to subjectively evaluate road safety. Two approaches are presented in this literature review to contrast the different approaches and to demonstrate the benefits and limitations of each. One approach is the observation of traffic conflicts and the second is a drive-through subjective rating system.

One observation and subjective rating technique used in road safety is the 'traffic conflict technique'. The goal of this technique is to obtain an indication of how a location (usually an intersection) is operating, thereby providing information to support effective road safety analysis. Perkins (Perkins and Harris, 1967) originally defined a traffic conflict as any evasive action taken by a driver to avoid a collision. Thus, a conflict is a measure of road user risk, accounting for driver behavior, roadway condition and the environment at the moment of exposure.

The application of traffic conflicts for safety problems has evolved into a variety of methods, each with its unique set of rules and criteria. One of these methods was developed at the University of British Columbia (Brown, 1994), under the auspices of the Insurance Corporation of British Columbia (ICBC). The UBC / ICBC traffic conflict technique requires that trained observers make a subjective assessment of traffic conflicts or 'near misses'. Conflict severity is measured by the sum of a 2 scale rating system: the "time-to-collision" and "risk-of-collision".

The "time-to-collision" (TTC) is a measure of the time elapsed before a collision would have occurred had no evasive action been taken. The "risk-of-collision" (ROC) is a subjective measure of the collision potential, and is dependent on the perceived control that the road user appears to have over the traffic conflict event. Each scale is based on a three-point scale with a '3' representing great hazard and a '1' representing minor hazard, as shown below in Table 4.1.

Table 4.1 Traffic Conflict Rating System

Traffic Conflict Measure	**Risk Assessment**	**Risk Quantification (Score)**
Time to Collision	0.0 to 0.5 second to collision	3
	0.5 to 1.5 second to collision	2
	1.5 to 2.5 second to collision	1
Rick of Collision	Severe Evasive Action*	3
	Moderate Evasive Action*	2
	Minor Evasive Action*	1

* Note: Evasive action includes braking, serving or other such actions.

The application of the traffic conflict technique provides demonstrable evidence of the operational shortcomings of the intersections being studied, and in turn enhances the assessment of intersection improvements (Brown, 1994). Since 1990, ICBC in partnership with provincial road authorities, have conducted numerous safety studies using the traffic conflict technique. The technique has matured into a useful diagnostic tool to assess traffic operation at an intersection. The technique uses observation and judgment to evaluate road safety risk and thus provides support for the development of a subjective road safety risk index.

Another approach to subjectively evaluate road safety involves a drive-through technique. Several attempts have been made to create road safety rating systems by using a drive through technique. What follows is a description of a typical effort and reports on the successes and failures associated with the approach.

A study completed by the Transport and Road Research Laboratory (TRRL) (TRRL, 1990) investigated the impact of road design characteristics on driver perception and behavior, and the propensity for driver risk acceptance. A 26-kilometer route was selected for investigation and 60 drivers were used to make an assessment of the road safety risk at specific locations along the route. The route was selected for its wide range of geometric features such as horizontal curves, vertical curves, lane widths and sight distance. The subjective rating system was compared to a more objective rating measure (i.e., the collision rate) to understand the agreement between rating techniques.

The **subjective safety rating** was determined by having each test participant drive the route at a 'comfortable', self-selected speed and then was asked to give a rating of the road safety risk at 45 locations along the route. The rating was based on a subjective eleven-point scale, with a score of zero representing "no chance of a near miss" and a score of 10 representing a "good chance of a near miss". The "near-miss" definitions came from traffic conflict research (Spicer, 1971). The **objective safety rating** was determined by calculating a safety performance measure, namely the collision rate based on historical collision statistics. In addition, a driver's selection of vehicle speed was also recorded as it could be used to reflect the perceived safety risk between locations. Higher speeds would reflect lower perceived risk, while lower speeds indicate higher risk (as perceived by the driver).

The subjective and objective scores obtained at the 45 locations were used to rank the road-user risk each location and then compare techniques. Two tests were then completed: test one was to determine the agreement between observers in ranking the 45 locations and test two was to compare the rank of the subjective risk scores with that of the objective risk scores. The agreement between drivers (test 1) was reported to be significant, but it is unknown how this was determined. For test 2, the Spearman correlation coefficient (ρ_s) was used to determine the agreement level between subjective and objective risk scores.

The formulation of (ρ_s) used in this study is shown in equation (4.1). It is noted that this formulation is only valid if there are no ties or if the proportion of ties is small in comparison to the number of paired sets. The (ρ_s) coefficient was 0.37, indicating that the agreement between the subjective risk scores and the objective scores was significantly less than perfect (1.0 is perfect correlation).

$$\rho_s = 1 - \frac{6\sum d^2}{n(n^2-1)} \tag{4.1}$$

where: ρ_s = Spearman's rank correlation coefficient,

d = differences between ranks,

n = number of paired sets.

In contrast, the driver's selection of vehicle speed correlated very well with the assignment of overall road safety risk. Speed selection is governed by many factors such as the degree of horizontal / vertical curves and sight distance, likely the same factors that influence risk assignment. Therefore, it is not surprising that a Spearman rank correlation coefficient of 0.80 was calculated, indicating strong correlation between subjective risk assignment and speed selection.

The reduction in vehicle speed selection and a driver's adaptation to potential hazard may be the principle reason for the lack of correlation between subjective risk assignment and the objective risk rating. In other words, drivers recognize potential hazards and adjust their driving behavior to compensate for increased risk level (i.e., reducing speed). This modified behavior then may result in better safety performance recorded by fewer collisions and / or less severe collisions.

Two subjective road safety risk techniques have been presented for contrast in this literature review, including the traffic conflict technique and a drive-through risk assignment technique. Each technique has demonstrated that the road safety risk can be evaluated and each approach offers some guidance on the development of the road safety risk to be presented herein.

4.2 Objectives for the Development of a Road Safety Risk Index

Several objectives were specified in the development of the driver-based, subjective risk index. These objectives are listed below.

1. Ensure that the road safety risk process is replicable and independent of the observer.
2. Construct the process such that the results are quantifiable and can be used to prioritize locations of high-risk.
3. Ensure that the road safety risk process is flexible and could be tailored to individual project needs.
4. The road safety risk index must be designed in such a way, as to not make the process cost-prohibitive.
5. Ensure that the road safety risk index is valid by comparing the results with objective methods to assess safety performance.
6. Ensure that the risk index is designed to support meaningful safety analysis.

Understanding these objectives, the task at hand was to develop a process that could accurately identify locations of high risk for various road types and conditions, and that the results were quantifiable, easily repeated and were not too costly to collect.

4.3 Methodology to Develop the Road Safety Risk Index

4.3.1 The Concept for a Road Safety Risk Index

In the conceptual development of a risk index, it was necessary to consider the fundamental elements that can describe road safety in a quantifiable manner. Many road safety researchers (Hadden, 1980, Hauer, 1982, Koornstra, 1992, Navin, 1997) isolated three elements used to define safety risk. Although there is some ambiguity over the terminology, the three fundamental elements used to describe road safety risk include **exposure** (exposure to hazards), **probability** (likelihood of encountering hazard) and **consequence** (severity of hazard if encountered). A relationship to describe road safety risk is formulated as follows:

RISK = Function of {Exposure, Probability, and Consequence}

where: exposure: - represents a measure to quantify the "exposure" of road users to potential hazards.

probability: - represents a measure to quantify the chance of a vehicle being involved in a collision.

consequence: - represents a measure to quantify the severity level resulting from potential collisions.

These three elements can be described by a simple example as illustrated in Figure 4.1. Consider a two lane rural highway that is tangent for one kilometer in an eastbound direction before transitioning into a sharp curve headed northbound. Just in advance of the curve another road merges onto the rural highway increasing the traffic volume before the curved section of highway. The roadside area adjacent to the tangent section of roadway has a gentle side-slope of 10:1 and a 20-meter wide clear zone (an area clear of roadside hazards). Conversely, the curved section of highway is directly adjacent to a cliff with a 100-meter drop to a river canyon and is not protected by a roadside barrier.

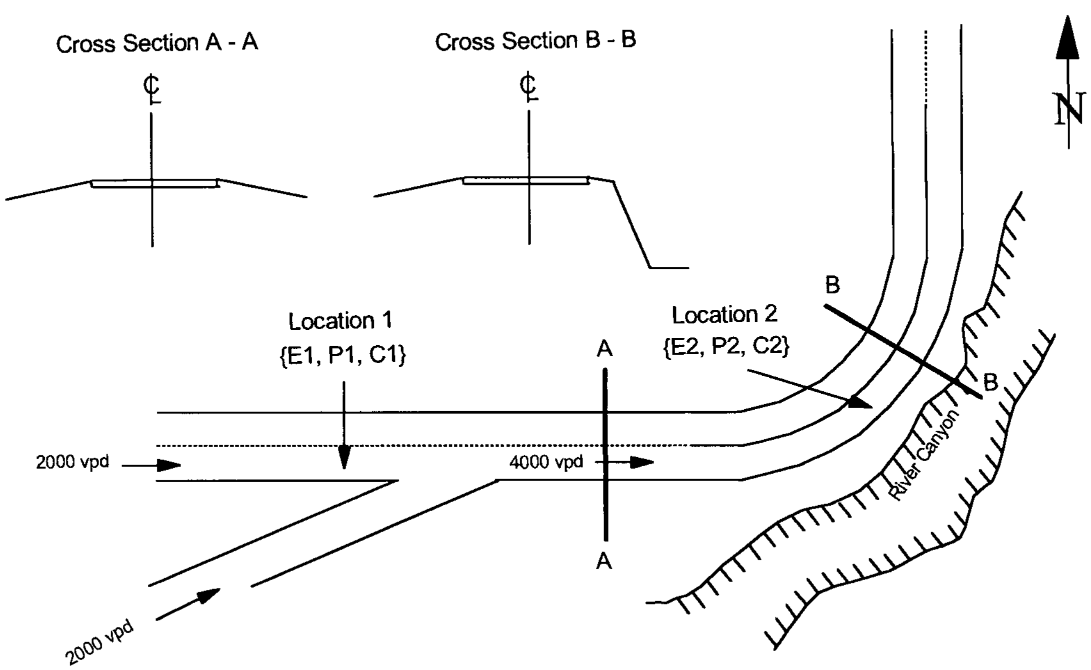

Figure 4.1: Element of Road Safety Risk Evaluation

Consider locations 1 and 2 as shown in Figure 4.1 and the three corresponding elements of safety (exposure (E), probability (P) and consequence (C)). Firstly, the exposure at location 1 is less that that at location 2 (E1 < E2, 2000 vpd < 4000 vpd). Secondly, due to the horizontal curve at location 2, the probability of a vehicle leaving the roadway and entering the roadside is higher as compared to location 1 (P1 < P2). Finally, considering the consequences of a vehicle leaving the roadway at locations 1 and 2, it is clear that the consequence at 1 would likely be minimal, whereas the consequence at location 2 would be very hazardous. Given this illustration, the result that the road safety risk at location 2 is considerably higher than at location 1 is logical and intuitive.

4.3.2 Methodology for a Road Safety Risk Index (RSRI)

In formulating the methodology, a three-step sequential process was established:

- Step 1: Identify roadway characteristics that may have a detrimental impact on safety and that can be evaluated during a drive through review.
- Step 2: Formulate guidelines, based on the elements of the risk function that can be used to evaluate each road feature identified in Step 1.
- Step 3: Develop the procedures that can be used by practitioners to obtain an accurate, reliable and cost-effective road safety risk index.

Step 1: *Identify Factors to be Considered for the RSRI*

When determining the road features that impact safety and which should be used to develop the RSRI, it is necessary to separate the roadway into urban and rural environments. There are two reasons to distinguish between environments. First, each environment requires a focus on different road factors, as roadway design characteristics are considerably different between urban and rural environments. Secondly, the ability to assess and collect risk information is different within each environment. In a rural environment, changes in road character are few, and the driving task is generally simple and thus the assessment and recording of risk is possible while driving at or near the posted speed. The opposite is true for an urban setting and the assessment of risk cannot be completed while driving.

Table 4.2 provides a list and description of roadway characteristics that may be considered in the assessment of road safety risk for each roadway environment. Not all factors listed in the table must be included in the formulation of the risk index and alternatively, other characteristics not included may be added to the list. The determination factors to include depends on site-specific characteristics and can be assisted by consultation with local and knowledgeable authorities.

Table 4.2: Road Features to Formulate a Road Safety Risk Index.

Environment	Road Feature	General Description of Risk
Rural Environment	Horizontal and / or Vertical Curve	Locations where the horizontal or vertical alignment may cause safety concerns
	Highway Access	High frequency of access points or access points that are particularly hazardous
	Overtaking	Passing locations that are considered risky or unsafe, or a lack of opportunity to pass.
	Roadside Hazard	Locations where the roadside area creates a risk in the event of an off-road excursion.
	Road Surface / Super-elevation	Road surface conditions are problematic due to rutting, ponding, super-elevation.
	Design Consistency / Expectation	Inconsistent road features that may violate the driver's expectation.
Urban Environment	Intersection Configuration	Intersection configuration or alignment may create potential safety problems.
	Traffic Control	Sites with a lack, inappropriate or poorly visible traffic control devises.
	Roadway Access	Locations lacking access control or access points that impact on safety performance.
	Cross-sectional Elements	The cross-sectional elements of a road may give rise to road safety concerns.
	Road Friction / Maneuverability	Locations where road friction (i.e. parking) or poor maneuverability creates safety risk.
	Illumination and Road Markings	Illumination levels are low or road marking and signs are inappropriate or misleading.
	Road Surface	Sites where road surface condition is poor, evidenced by rutting, cracking, or ponding.

Step 2: *Formulate Guidelines for the RSRI*

Once the factors that impact road safety are selected, either from the list in Table 4.2 or other factors not listed, then it is necessary to formulate the guidelines and techniques to evaluate the road safety risk. For each factor, the components of risk, namely exposure, probability and the consequence associated with the factor, must be evaluated in formulating a risk score.

Exposure is the simplest and most objective measure used in formulating the risk score. Exposure is evaluated by using the traffic volume which encounters a hazardous road feature. In a rural environment, generally the main line traffic volume is sufficient to quantify the exposure level to a hazard. The exception may be at major intersections where the traffic volume on the intersecting road may be important in determining the exposure to risk. In an urban environment and because intersections are the predominant high risk areas, the traffic volume on both the major and minor roads is required, and in some cases the traffic volumes by direction and lane movements is useful (i.e., northbound, left-turning traffic volume).

The **probability** element of risk represents a measure to quantify the chance of becoming involved in a collision. Each road feature must be evaluated separately to assess the probability of the specific road feature in causing an incident. General guidance on how to assess the risk probability is provided for each factor listed in Table 4.2 and is based on the input and consensus from a group of four road safety experts. However, it is important to recognize that each factor should be evaluated based on location specific characteristics and therefore, the guidance may deviate from what is provided herein. In other words, location specific characteristics may necessitate the modification of how to assess the probability component of different road features in formulating the road safety risk. The guidance to assess the probability component of road safety risk is provided in Table 4.3 (for each of the factors listed in Table 4.2).

Table 4.3: Evaluating the Probability Component of Road Safety Risk

Environment	Road Feature	Evaluation of Probability
Rural	Horizontal and/or Vertical Curve	- radius of curve(s) based on design speed - presence of compound curves (s-curves) - combination of horizontal and vertical curves
	Highway Access Locations	- access frequency / density - access alignment / connection - sight-distance from access location
	Overtaking	- length of passing zone - sight-distance in passing zone - opportunity for passing
	Roadside Hazard	- shoulder width and condition - degree of horizontal and vertical curve - conflict points from passing and/or access
	Road Surface & Super-elevation	- presence of rutting, ponding, cracking, holes - inappropriate super-elevation
	Design Consistency / Expectation	- unexpected feature requiring driver action - inconsistent road design features
Urban	Intersection Configuration	-oblique alignment of the intersection -level of channelization
	Traffic Control	-inappropriate and/or degree of traffic control - visibility of traffic control devises
	Roadway Access	- access frequency / density - access alignment / connection - sight-distance from access location
	Cross-sectional Elements	-narrow lane widths -facilities for alternate modes (sidewalks) -proximity of roadside hazards (i.e. poles)
	Road Friction / Maneuverability	- features creating road friction (i.e., parking) - ability to maneuver with ease (change lanes)
	Illumination and Road Markings	- low or inappropriate level of illumination -consistent and clear signs and markings
	Road Surface / Drainage	- presence of rutting, ponding, cracking, holes - opportunity for poor drainage

The third component of road safety risk that must be evaluated is the **consequence** of an incident should it occur. Vehicle speed is one factor that is known to influence the consequence of an incident. Therefore, in a rural road environment, the posted or operating speed may be used as one measure of consequence. Alternatively, road features can provide a surrogate measure for speed, including higher vehicle speeds within passing zones and the potential for high-speed differential speeds caused by the presence of access points onto a highway. Therefore, the consequence level may be evaluated based on the results from the assessment of passing or access features (for example).

In addition to vehicle speed, the level of forgiveness of a roadside area is also an important factor in determining the consequence in a rural road environment as a large portion of the collisions are single vehicle, off-road crashes (ICBC, 1995). Thus, the consequence level may also be evaluated based on the results from the assessment of the roadside features.

Evaluating consequence in an urban environment is more difficult as there is low variability in posted vehicle speeds and the roadside area is less of a concern in urban areas as most collisions occur on the traveled portion of the roadway. Therefore, the evaluation of consequence in an urban area should be completed using others factors as surrogates. For example, the visibility of traffic signals or poor sight distance for an access location may result in high consequence collisions at high speeds.

Step 3: *Procedures to Obtain RSRI*

In formulating the methodology for the RSRI several questions arose concerning how to quantify or score the elements of risk during the drive through review. The questions are presented below, together with a response for a solution for the direction of the road safety risk index. It should be noted that a demonstration of the methodology and process will be provided for a real life application in a subsequent section.

For each road feature, how should the component of risk be evaluated?

Based on the experience from traffic conflict techniques and suggestions by Wedley for an analytical hierarchy approach for qualitative information (Wedley, 1990), it was felt that four risk levels were appropriate. Essentially, a score of '3' would represent high risk, a '2' would represent moderate risk, a '1' would represent minor risk, and a score of '0' could be used to indicate that the roadway feature poses inconsequential risk.

Can each risk level be definitively distinguished during a drive through?

There must be adequate opportunity to differentiate between the four risk levels. Guidelines associated with each factor are defined in a way that the road safety risk is assigned in a relative and subjective manner. In other words, the risk associated with specific road feature is evaluated relative to the corridor under review and the score is based on a subjective judgment of the road feature. For example, an observer evaluating horizontal curvature can determine that curve 'A' is sharper that curve 'B' and that curve 'C' is less sharp than curves 'A' or 'B' and assign the risk scores accordingly.

Are some road-features more important to safety than others?

At times, a specific road feature may be considered more hazardous than another (i.e., the poor horizontal curves are more problematic than the access points). If this is the case, a weighting factor can be applied to the risk scores for the problematic road feature to reflect this risk unbalance.

Can the RSRI reflect the compounding effect of many road features on safety?

A combination of several road features can amplify the detrimental impact on safety such as poor intersection alignment and inappropriate traffic control. Again, if considered appropriate, a weighting factor can be applied to the sum of the specific risk assignment scores to reflect the compounding effect of several road features and safety performance.

Unless there is a definitive and justifiable need to apply a weighting factor to either one specific road feature or a combination of problematic features, it is recommended to avoid the use of weighting factors.

In making a subjective risk assessment of various road features, it is useful to have an understanding of the relevant road design standards. For example, the sight distance required for a rural highway with a design speed of 100 km/hr is 200 meters or the minimum length of a passing zone is 350 meters (Ministry, 1991). This knowledge can assist in the subjective assignment of risk.

4.3.3 Formulation of RSRI

The exposure component of the RSRI can be determined in two ways depending on the problem under investigation. When a location is being studied in relation to a large reference population, specific volume levels can be developed to identify high, medium and low exposure levels. Table 4.4 provides an example of some specific volume levels for both an urban and a rural road environment, thereby identifying different exposure levels. It is noted that the selection of the categories for exposure level is dependent upon the reference population. The categories shown in Table 4.4 are suitable for conditions that exist on British Columbia highways (rural) and in the major cities within BC (such as Vancouver or Victoria).

Table 4.4: Exposure Levels for RSRI

Urban Environment				Rural Environment	
Minor Road Volume (vpd)	Exposure Levels for Major Road Volume (vpd)			Mainline Volume Range (vpd)	Exposure Level
	< 5,000	5,000 to 15,000	> 15,000		
< 5,000	1	1	2	< 5,000	1
5,000 to 15,000	1	2	3	5,000 to 15,000	2
> 15,000	2	3	3	> 15,000	3

Notes: vpd = vehicles per day

Alternatively, when a specific corridor or group of locations are being investigated for improvement, the exposure can be determined relative the corridor or group of locations. The exposure level is calculated by using the traffic volume data as shown in equation (4.2) and (4.3) for urban and rural environments respectively. This provides a relative exposure score ranging from a minimum of 0 to a maximum of 3.0, with a high score representing high exposure.

$$Exposure_{Urban} = \left(\frac{\left(V_{i(mjr)}\, x V_{i(mnr)}\right)}{\left(V_{(mjr)}\, x V_{(mnr)}\right)_{\max}} \right) x 3.0 \tag{4.2}$$

$$Exposue_{Rural} = \left(\frac{V_i}{V_{\max}} \right) x 3.0 \tag{4.3}$$

where:

$V_{max(mjr)}$ = maximum volume on the major road in reference group

$V_{max(mnr)}$ = maximum volume on the minor road in reference group

V_{max} = maximum volume on the corridor under review

V_i = volume at the location of a specific road feature

The probability component of risk is obtained by using the guidelines provided in Table 4.3 and by making an assessment of each road feature using the 4-point scale. This provides a probability score for each road feature ranging from 0 to 3.0, with a high score representing a high probability of an incident. Specific levels associated with each element can be developed to categorize the probability component of risk.

The consequence component of risk can be evaluated by defining specific levels for consequence either for the particular location(s) under review or for a larger reference population. Several factors are used to gauge the consequence such as vehicle speed, potential for speed differential, mix of vehicle sizes, and roadside hazards. Thresholds can be established for each of these factors and are used in combination to define consequence level. An example is shown in Table 4.5, using several measures that exist for a rural environment.

Table 4.5: Consequence Levels for RSRI

Posted Speed (kph)		Speed Differential (kph)		Percent Heavy Vehicles		Roadside Hazard Risk	
Speed	Conseq. Level	Speed Difference	Conseq. Level	% Heavy Vehicles	Conseq. Level	RHR	Conseq. Level
< 50	1	< 5	1	2%	1	Low	1
50 – 80	2	5 – 10	2	5%	2	Medium	2
> 80	3	> 10	3	10%	3	High	3

The factors can be averaged to determine the composite consequence rating. Rather than identifying specific ranges for each factor, it is possible to calculate the relative consequence by using equation (4.4: using posted speed as the example), thus providing the results in a 4-point scale (0 to 3).

$$Consequnce_{Rural} = \left(\frac{PS_i}{PS_{\max}}\right) x3.0 \tag{4.4}$$

where: PS_i = posted speed at the location of a specific feature

PS_{max} = maximum posted speed on corridor under review

The RSRI can be formulated in two ways. The first index, $RSRI_{specific}$, defines the risk associated with each road feature, obtained by combining the scores for the three components of risk. $RSRI_{specific}$ identifies problem sites and facilitates the application of known improvements to address specific road deficiencies. The second index, $RSRI_{combined}$, defines overall risk by combing the $RSRI_{specific}$ scores for all road features. The formulations are shown in equations (4.5) and (4.6).

$$RSRI_{specific} = E_i \; x \; P_i \; x \; C_i \tag{4.5}$$

$$RSRI_{combined} = \sum_{i=1}^{n} E_i \; x \; P_i \; x \; C_i \tag{4.6}$$

where: E_i = risk score due to exposure for road feature i

Pi = risk score due to probability for road feature i

Ci = risk score due to consequence for road feature i

n = number of road features investigated

4.4 Collecting Data for the Road Safety Risk Index

The following process is recommended to collect and record the information required to produce the road safety risk during a drive through review.

The first step, as described in the previous section, is to determine which road features are relevant for the risk assessment. Often, many of the elements may be excluded from consideration, thereby allowing greater attention to be focused on elements that are likely to significantly contribute to poor safety performance.

The second step is to determine the resources that are required to conduct the drive through review. The number of road safety risk observers and/or the number of drive through passes will depend on the number of road features to be evaluated. It is difficult for one observer to detect, evaluate and record more than one or perhaps two road safety features during one drive through pass.

The third step is to determine the method to record the risk assessment. In a rural environment, it is suggested that the assessment and recording be done during the drive through review. Alternatively, in an urban environment it is necessary to stop at regular intervals to record the road safety risks.

The fourth step is to obtain route information that includes longitudinal reference points along the study corridor. This will allow for the location referencing of hazards along the route. In BC, a system from the Ministry of Transportation and Highways known as the Landmark Kilometer Inventory (LKI, 1995) is ideal system to reference a position on a highway. Recording an odometer offset from a fixed landmark (intersection, bridge, etc.) will identify location of hazards.

In the interest of efficiency, it is also beneficial to prepare data collection sheets that can be used to record the road safety risk scores. Checking appropriate boxes on a data collection form and recording the location offset will facilitate efficiency of the observation process.

There are other suggestions for completing the drive through review based on the experience undertaken for the case study of this research. First, the drive through review should be completed at or near the posted speed limit. Secondly, effort should be taken to ensure that roadway and roadside features are clearly visible (i.e., not covered in snow). One exception is a nighttime drive through review, which can identify some locations of high risk. Thirdly, the route should be driven in both directions and the safety concerns should be referenced by direction. Finally, as this process can be quite tiring, it is recommended that a limited amount of roadway be covered in one day as the quality of the risk assessment may deteriorate after extended observation.

4.5 Case Study and Application of Road Safety Risk Index (RSRI)

This section is intended to demonstrate an application of the road safety risk index, including a description of the case-study location, the data collection process and the risk assignment. This will be followed by an analysis of the results and a comparison with more tradition road safety measures.

4.5.1. Location and Background Information of the TCH Corridor

The corridor selected to test the road safety risk index was the Trans Canada Highway (TCH) between the town of Cache Creek, located near Kamloops, and the Alberta Border. The corridor is approximately 430 kilometers in length and is the principle east-west highway connecting Vancouver with the rest of Canada. The corridor is mainly rural, but passes through many small communities. The corridor is shown in Figure 4.2.

This corridor was selected for several reasons. The character of the highway was highly variable, with areas of both generous and compromised road design standards due in part, to the variation in topographical constraints along the route. In addition, the BC Ministry of Transportation had identified the route for a major upgrading and as such, it was believed that the road safety risk index might be useful for the Ministry in assessing road safety. Ministry staff could also provide a critique of the usefulness of the RSRI.

4.5.2 Data Collection for the RSRI for the TCH Corridor

The corridor was first reviewed using the Ministry of Transportation and Highway's (MoTH) photo-log system. This system provides an opportunity to view photographic images of the corridor to understand the character of the corridor and to determine which road safety factors that should be investigated during the drive through review. In addition, a meeting with MoTH staff was conducted in August 1998 to gain an understanding of the safety concerns and hazardous features along the corridor.

Understanding the road features of concern on the corridor, and the limited resources available to conduct the drive through safety review, it was determined that three factors would be investigated to test the road safety risk index. It was felt that these factors would adequately demonstrate the process, which could then be applied in a similar manner to other factors and other corridors.

The three road features targeted for the drive through for the TCH corridor included the following:

1. Problems associated with access points onto the highway,
2. Problems with the opportunity / ability to complete passing maneuvers, and
3. Problems associated with roadside hazards.

The drive through review was conducted in October 1998, when the conditions were favorable to observe the road features. A three-person team was used to assess and record the road safety risk. The driver was responsible for evaluating the road safety risk associated with passing with the front-seat passenger recorded the results for the driver. The front-seat passenger was responsible to assess the risk associated with access points along the corridor. The back-seat passenger was responsible to make an assessment of the road safety risk associated with the roadside environment. The first pass of the 860-kilometer route (430 kilometers in each direction) was completed within 4 days.

Data collection was completed while driving at (or near) the posted speed limit throughout the length of the corridor. The location referencing system, known as the Landmark Kilometer Inventory (LKI), was obtained from the BC Ministry of Transportation and Highways (MOTH) and was used for the data collection process along this route.

The route description is provided below in Table 4.6 and will be used to convey the RSRI results.

Table 4.6: Route Description (LKI)

Route No.	Segment No.	Offset		Length Km.	Segment Description From: Major Center To: Major Center
		Start	End		
1	0925	0.00	25.90	25.90	From: Kamloops To: Monte Creek
1	0935	0.00	85.72	111.62	From: Monte Creek To: Salmon Arm
1	0950	0.00	27.19	138.81	From: Salmon Arm To: Sicamous
1	0960	0.00	71.13	209.94	From: Sicamous To: Revelstoke
1	0975	0.00	48.35	258.29	From: Revelstoke To: Glacier Park (West Gate)
1	0980	0.00	43.81	302.10	From: Glacier Park (West Gate) To: Glacier Park (East Gate)
1	0985	0.00	56.06	358.16	From: Glacier Park (East Gate) To: Golden
1	0990	0.00	25.93	284.09	From: Golden To: Yoho Park (West Gate)
1	0995	0.00	45.3	429.39	From: Yoho Park (West Gate) To: Alberta Border

4.5.3 Development of the RSRI for the TCH Corridor

A description of the road safety risk generated by the three road features used for this research is provided below.

4.5.3.1 Risk Assignment for Access

Exposure: The exposure component of risk associated with access is calculated throughout the corridor by using the mainline traffic volume and equation (4.3). It should be noted that the exposure calculation is similar for the other two road features reviewed.

Probability: The three evaluation guidelines suggested in Table 4.3 were used to assess the probability component of risk for each highway access point. The potential risk associated with each access point was evaluated by subjectively assessing the following:

- The frequency and/or density of access locations along the highway corridor (excluding urban areas).
- The horizontal and vertical alignment of the access road in relation to it's connection to the highway.
- The turning sight distance available to motorists attempting to gain access to the highway from each access point.

These factors gave sufficient guidance such that an observer could make a subjective judgment of each access point and assign a road safety risk score of '3' for high risk, '2' for moderate risk, '1' for minor risk and '0' for no risk. In areas where there were many access points, it was necessary to slow down or stop, in order that each access point could be adequately evaluated.

Consequence: The posted speed and two other road features factors were used to assess the consequence component of risk. The other factors included whether the access-point is located in a passing section or the access point is located in an area where the roadside safety risk was high. These risk scores were being collected concurrently by the other observers.

4.5.3.2 Risk Assignment for Passing Opportunities

Exposure: The exposure component of risk associated with each passing opportunity is calculated on the corridor by using the mainline traffic volume and equation (4.3).

Probability: Each passing opportunity on the Trans Canada Highway corridor between Cache Creek and the Alberta border was reviewed with respect to the probability of causing an incident. This included all passing zones, passing lanes and climbing lanes. In assessing the probability component of risk for each passing opportunity, three guidelines (as suggested in Table 4.3) were used to evaluate the safety risk. These guidelines included the following:

- The overall length of the passing zone, recognizing that the minimum standard was approximately 200 meters (BC MOTH, 1994).
- The sight distance that is available while attempting to complete a passing maneuver.
- The frequency and duration of passing opportunities available along the corridor.

These three factors provided sufficient guidance to the observer (the driver in this case) to subjectively assess the risk associated with passing. The four-point ranking system was used as described previously. The driver was able to adequately assess passing risk during the driving task and specific comments related to passing opportunities was recorded by the front seat passenger.

Consequence: To assess the consequence component of passing risk, the posted speed and two other road factors (collected concurrently) were used. One other factor was the presence of access points within the passing zone. This is particularly hazardous when a vehicle turns right out of an access by checking toward the left for gaps in oncoming traffic but fails to check right for the potential for a passing maneuver. The second factor to assess the consequence of passing risk, was the severity of the roadside. This is important given that an incident involving a passing maneuver's often results in an off-road excursion.

4.5.3.3 Risk Assignment for Roadside Hazard

Exposure: The roadside hazard was evaluated continuously along the Trans Canada Highway corridor between Cache Creek and the Alberta border. Again, the exposure component of risk associated with the roadside is calculated by using the mainline traffic volume and equation (4.3).

Probability: The three evaluation guidelines proposed in Table 4.3 were used to determine the probability component of risk for the roadside environment. The potential risk was evaluated subjectively by assessing the following three components of the roadway character:

- The degree of horizontal and vertical curves that may contribute to a vehicle leaving the roadway.
- The width of the shoulder, the surface-type of the shoulder (gravel or asphalt) and the condition of the shoulder.
- The frequency of conflict points (access locations or the termination of a passing zones), creating the potential for an off-road excursion.

These three factors provided adequate guidance for the observer to make a subjective assessment using the four-point scale. Unlike the evaluation of access points and passing opportunities, the roadside was evaluated continuously through the corridor with the changes in risk assessment referenced to the LKI location referencing system.

Consequence: In addition to the posted speed, other roadway features were used to determine the overall assessment of consequence associated with the roadside. Road features affecting the consequence include the degree of embankment side-slope, creating the potential to cause a roll over for an errant vehicle. Another factor that affects the assignment of consequence is the type of roadside hazard that exists in the roadside. This included either a hazardous object (i.e., a rigid pole) or a surface element (i.e., the ditch type) which, if encountered by an errant vehicle, could result in severe consequences.

4.5.4 Results of RSRI for the TCH Corridor

The road safety risk index was calculated based on equation (4.5) for each specific road feature and equation (4.6) for the combined index. The results are summarized based on 31 homogeneous segments, defined by roadway design and traffic characteristics. The corridor segmentation was completed with the assistance and knowledge from local staff from the Ministry of Transportation and Highways. The risk index is evaluated continuously throughout the corridor and the results are presented in Table 4.7 below.

Table 4.7: Results of the RSRI for the TCH Corridor

Segment No.	Segment Length (km)	Segment Volume (vpd)	Risk Index Scores			
			Access	Passing	Roadside	Total
1	5.1	18000	1.05	10.01	11.00	22.06
2	27.5	6039	6.09	24.36	73.54	103.99
3	11.3	6639	3.01	10.14	23.50	36.65
4	7.0	5922	2.74	1.93	32.65	37.32
5	3.4	8303	1.38	1.23	2.20	4.82
6	29.0	10941	44.69	39.85	120.17	204.71
7	7.7	11008	0.00	0.53	2.34	2.86
8	5.9	7463	4.03	4.17	5.55	13.74
9	19.8	4311	9.38	6.74	21.75	37.87
10	1.6	5183	0.00	0.00	0.00	0.00
11	3.3	6055	0.14	0.09	0.21	0.44
12	8.5	5546	1.91	3.34	5.20	10.44
13	8.8	5291	0.34	0.34	0.00	0.68
14	8.4	5037	0.39	0.51	0.71	1.61
15	17.7	4874	2.85	3.10	11.00	16.94
16	8.3	4711	2.46	1.95	7.25	11.66
17	6.0	5247	0.11	0.33	3.25	3.70
18	6.6	5782	2.12	4.84	9.01	15.97
19	2.6	6318	0.00	0.25	1.01	1.26
20	1.0	6854	0.00	0.00	0.00	0.00
21	5.0	4574	0.33	0.31	1.38	2.02
22	12.8	4646	1.26	5.70	14.10	21.06
23	12.8	4646	0.26	0.64	3.37	4.27
24	17.9	4718	1.51	2.64	16.91	21.06
25	43.9	4791	1.91	7.94	28.62	38.47
26	29.7	4791	2.78	19.00	53.43	75.20
27	24.2	4863	7.85	18.81	59.18	85.84
28	2.3	4458	0.13	0.13	0.00	0.26
29	2.4	4364	0.00	0.00	0.77	0.77
30	23.6	4052	5.69	7.61	54.26	67.56
31	45.4	3899	0.49	1.89	5.04	7.42

4.6 Success and Validity of the RSRI (Comparative Results)

This section evaluates the success and validity of the road safety risk index. The evaluation consists of two components. First, given the guidelines provided for each element affecting road safety, the replicability of the risk assessment between observers will be measured. Secondly, the locations of high risk identified by the risk index will be compared to the results from a traditional road safety measure: the collision frequency.

4.6.1 Comparing RSRI Scores Between Observers

An important success factor of the road safety risk index is the reliability of the risk assessment and data collection process. The reliability of the process can be measured by the similarity of the results produced by different observers for the same section of roadway. The inability to record similar safety risk produced by two different users will jeopardize the validity of the process. To address this concern, the level of agreement between observers will be determined.

In order to complete this evaluation, one segment from the study corridor was selected for reliability testing. The segment selected was number 935, the 85-kilometer segment between Monte Creek and Salmon Arm. A second observer would make an assessment of the probability component of each of the three factors (access, passing and roadside), given the same guiding information (Table 4.3).

To evaluate the reliability of the risk index for access, each access point on Segment 935 producing a probability risk score of '3', '2', or '1', was included. This criterion produced a total of 77 access points that would be used in the evaluation. To evaluate the reliability of the risk assignment for passing, each passing zone on Segment 935 were included. This included a total of 72 passing zones in both directions. Finally, to evaluate the reliability of risk assignment for roadside hazards, the segment was divided into 85, one-kilometer segments with a risk score produced for each one-kilometer section by two different observers.

To determine the consistency and therefore the reliability of the risk assignment between observers, the statistic kappa was used (Cohen, 1960), (Fleiss, 1971), (Spring, 1993). The kappa statistic (κ) provides an indication or measure of the agreement between the two observers. The kappa statistic utilizes the subjective risk assignment score produced by each observer, categorized into three categories: high risk (score 3), moderate risk (score 2) and minor risk (score 1). The kappa statistic is defined as follows:

$$\kappa = \left(\frac{P - P_e}{1 - P_e} \right) \tag{4.7}$$

where: P = overall percent agreement (0.0 – 1.0)

P_e = overall percent agreement expected by chance (0.0 – 1.0)

The overall percent agreement (P) is calculated by summing the number of observations where agreement exists divided by the total number of observations. The overall percent agreement that can be expected by chance (P_e) can be calculated by the percentage of assignment by each observer into the number of categories. An example will be provided below. A positive value for the kappa statistic indicates agreement between observers, a value of zero represents the level of agreement that could be expected by chance, and a negative kappa indicates disagreement between observers. The variance of the kappa statistic is required to determine agreement between observers. The variance of kappa is calculated as follows:

$$Var(\kappa) = \frac{1}{N} x \frac{\left\{ \sum p_j^{\,2} - \left(\sum p_j^{\,2} \right)^2 \right\}}{\left(1 - \sum p_j^{\,2} \right)^2} \tag{4.8}$$

Where: N = is the total number of observations

j = the number of categories of classification

p_j = the proportion of all assignments of the j-th category

Under a hypothesis of no agreement beyond chance, a value can be calculated to test the significance level of the agreement between the two observers. This value, defined as $k/\sqrt{Var(\kappa)}$, is approximately distributed as a standard normal variant (Fleiss, 1971) and can be compared to the critical z-value to determine the level of significance.

To demonstrate, consider the road safety risk scores of '3', '2', or '1' assigned to the 77 access locations on Segment 935. The results from the two observers are shown below in Table 4.8.

Table 4.8 Level of Agreement between Two Observers for Access

Observer Two Risk Score	**Observer One Risk Score**			**Total**
	'3'	**'2'**	**'1'**	
'3'	9	3	2	14
'2'	4	14	11	29
'1'	1	7	26	34
Total	14	24	39	77

The overall percent agreement is calculated by summing the values along the diagonal in the table divided by the total number of observations. Therefore P is calculated as follows:

$$P = \frac{9+14+26}{77} = 0.636$$

The overall percent assignment between observers that can be expected by chance (P_e) is calculated as follows:

$$Pe = \left(\frac{14}{77} x \frac{14}{77}\right) + \left(\frac{24}{77} x \frac{29}{77}\right) + \left(\frac{39}{77} x \frac{34}{77}\right) = 0.374$$

Therefore, the kappa statistic can be calculated by using equation 4.1 as follows:

$$\kappa = \frac{0.636-0.374}{1-0.374} = 0.419$$

The variance of the kappa statistic is calculated using equation 4.2 and the proportion of assignments into each category is shown below.

$$P_{3'} = 0.5x\left(\frac{14+14}{77}\right) = 0.1818 \qquad and \qquad (P_{3'})^2 = 0.0331$$

$$P_{2'} = 0.5x\left(\frac{24+29}{77}\right) = 0.3442 \qquad and \qquad (P_{2'})^2 = 0.1185$$

$$P_{1'} = 0.5x\left(\frac{39+34}{77}\right) = 0.4740 \qquad and \qquad (P_{1'})^2 = 0.2247$$

$$thus \qquad \sum (P_{j'})^2 = 0.3743$$

$$Var(\kappa) = \frac{1}{77} x \frac{(0.3743 - (0.3743)^2)}{(1 - 0.3743)^2} = 0.0077$$

In order to determine the level of agreement between observers and the level of significance, the ratio of $k/\sqrt{Var(\kappa)}$ can be calculated. This value is then compared to the critical z-value of 2.32, representing the 99% significance level. The result below indicates that since 4.76 is greater than 2.32, that there is strong agreement between observers and the process to assign road safety risk for access locations on a rural highway (Segment 935) is valid.

$$\frac{\kappa}{\sqrt{Var(\kappa)}} = \frac{0.419}{\sqrt{0.00777}} = 4.76$$

A similar reliability analysis was completed for the risk assignment scores for both passing and roadside hazard as provided by the two observers on Segment 935. The subjective measures evaluated included the passing sight-distance, and for the roadside included the shoulder width / condition, the degree of embankment slope, and the estimate of hazard level for objects within the roadside. The results are shown in Table 4.9, summarizing the overall percent agreement (P), the percent agreement that is expected by chance (P_e), the kappa statistic (κ), the proportion of assignment into each category, the variance of kappa, and the significance test for both road features.

Table 4.9: Level of Agreement for Other Subjective Measures

Calculated Value	Passing Sight Distance	Roadside Shoulder Width/Con.	Roadside Side-Slope Hazard	Roadside Hazardous Objects
P	0.611	0.894	0.647	0.694
P_e	0.470	0.814	0.362	0.448
(κ)	0.267	0.430	0.447	0.446
(P_3)	0.0347	0.0176	0.0706	0.0882
(P_2)	0.0903	0.0059	0.1059	0.0882
(P_1)	0.2292	0.0765	0.4056	0.1941
(P_0)	0.6458	0.9000	0.4294	0.6294
$(P_3)^2$	0.00121	0.00031	0.00498	0.00779
$(P_2)^2$	0.00815	0.00003	0.01121	0.00779
$(P_1)^2$	0.05252	0.00585	0.16474	0.03768
$(P_0)^2$	0.41710	0.81000	0.18439	0.39616
$\Sigma(P_{\cdot j})^2$	0.47897	0.81619	0.36532	0.44941
Var (κ)	0.0128	0.0527	0.0068	0.0096
$k/\sqrt{Var(\kappa)}$	2.36	1.89	5.43	4.55
Significance at 99% Level	**Yes 2.36 > 2.32**	**No 1.89 < 2.32**	**Yes 5.43 > 2.32**	**Yes 4.55 > 2.32**

The results indicate that the level of agreement between observers for three of the four subjective measures exceeded the 99 percent level of significance. The exception was that of the roadside shoulder where the significance test failed. The reason for the failure has less to do with the level of agreement between observers which was very high (P= 0.894) but rather, the failure was a result of the percent expected by chance (P_e = 0.814) which was similarly high. The reason for the high value of P_e, is that the shoulder width and condition (the basis of risk assessment) does not vary significantly on Segment 935. In other words, the failure of agreement between observers is more a result of the specific element and not the agreement level.

4.6.2 Comparing Ranks with Objective Measures (Collision History)

In this section, the results produced by the road safety risk index (RSRI) will be compared with the results produced from an objectively derived measure based on the collision history. If agreement between the subjective approach and the objective technique is strong, it will provide the validation for the use of the road safety risk index.

In order to evaluate the success and validity of the RSRI, a meaningful road safety performance indicator based on historical collision data should be used. The indicator used is defined as the 'potential for improvement', measured as the difference between the existing collision frequency and the expected collision frequency at a location. The expected collision frequency is determined by applying a valid collision prediction model and the existing collision frequency is based on the historical collision counts and refined by applying the Empirical Bayes technique. The magnitude of the difference between the existing and expected collision frequencies will facilitate the ranking of sites (a greater difference having a higher rank) and this rank will be compared with the ranking determined by the RSRI. This ranking approach is similar to that presented in the previous chapter on the use of claims data for safety analysis.

The starting point for this evaluation was the development of a collision prediction model that could be applied to the roadway under investigation in order to determine what would be the expected or the normal collision frequency at each site. The technique used to develop the collision prediction model is similar to that described in the preceding chapter, and is based on the generalized linear modeling approach (GLIM). Collision and traffic data was obtained for road segments of similar character to the roadway used in the RSRI case study (i.e., a rural, conventional highway). A model was then developed that predicts the three-year collision frequency at a site based on the segment length, measured in kilometers (L), and the main-line traffic volume given by the average annual daily traffic volume (AADT).

The formulation of the model, the model parameters and the indicators for the model significance, including the t-ratio, the κ value, the *Pearson* χ^2 and the scaled deviance are presented in Table 4.10. Note that a description of the indicators for model significance was provided in the previous chapter. Also note that a greater description of collision prediction models will be provided in a subsequent chapter of this thesis.

Table 4.10: Collision Prediction Model for Rural Highway

Model Formulation	t-ratio		κ	Pearson χ^2 (χ^2 test)	S.D. (DoF)
$Collisions/3yrs = 0.001302 \times (L\,x\,AADT)^{0.9645}$	a_o a_1	5.1 3.4	1.34	171 (186)	179 (156)

With the developed collision prediction model, the next step was to calculate the expected or normal collision frequency at sites along the corridor. Sites on the 430-kilometer corridor were based on the 31 homogeneous segments that were used in presenting the results of the RSRI. These 31 segments are considered homogeneous based on road design and traffic characteristics and the corridor segmentation was completed with the assistance and knowledge from local staff from the Ministry of Transportation and Highways. The segmentation resulted in variable segment length, ranging from a low of approximately 2.0 kilometers to segments close to 45.0 kilometers in length.

Collision data was extracted from the provincial Highway Accident System (HAS) database to determine the existing collision frequency at each site. Collision data from the years 1993 – 1995 was extracted, thus providing the total frequency of collisions on each of the 31 sites. These collision counts were then subjected to an Empirical Bayes (EB) refinement technique to obtain a better estimate of the existing safety performance. Note that the Empirical Bayes technique was described in the preceding chapter.

With the existing collision frequency (subjected to the EB-refinement) and the expected collision frequency at each location, it is then possible to determine the 'potential for improvement', for the 31 sites. The 'potential for improvement' is simply measured as the difference between the existing collision frequency and the expected collision frequency at a location (i.e., from the model). The rank is established based on descending order of the difference between existing and expected collision frequency. This rank is then compared to the ranking of the risk scores from the RSRI, as presented in Table 4.7.

The Spearman rank-correlation coefficient is used to determine the level of agreement between the road safety risk index and the objective collision history. The Spearman's rank-correlation coefficient is often used as a non-parametric alternative to a traditional coefficient of correlation and can be applied under more general conditions (Freund, 1982). To calculate the Spearman's rank-correlation coefficient, it is necessary to segment the data sets and then rank the paired data sets in ascending or descending order.

A summary of the total road safety risk index scores (Table 4.7), the existing collision frequency and the expected collision frequency for each of the 31 sites is shown in Table 4.11. Also included in the table is the ranking established for each of the 31 sites based on both the RSRI and the 'potential for improvement'. The paired data set is then used in calculating the Spearman rank-correlation coefficient (ρ_s) as shown below in equation 4.9. A score of 1.0 represents perfect correlation and a score of zero indicates no correlation. An advantage of using (ρ_s) is that when testing for correlation between two sets of data, it is not necessary to make assumptions about the nature of the populations sampled.

$$\rho_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)} \qquad (4.9)$$

where: d = differences between ranks

n = number of paired sets

Table 4.11: Summary of RSRI Score and the Collisions on Segmented Corridor

Seg. No.	Segment Length (km)	RSRI Score	RSRI Rank	Collision Frequency (coll./3yrs.) Count	EB-Est.	Expected (CPM)	PFI[1] Difference (EB-Exp.)	PFI[1] Rank	Rank Diff.[2] (d)
1	5.1	22.06	11	213	210.79	79.65	131.14	9	-2
2	27.5	103.99	2	300	298.50	141.10	157.40	6	4
3	11.3	36.65	10	110	109.11	65.56	43.55	18	8
4	7.0	37.32	9	70	68.85	37.00	31.85	20	11
5	3.4	4.82	20	40	39.28	25.54	13.74	24	4
6	29.0	204.71	1	767	764.45	263.45	501.00	1	0
7	7.7	2.86	23	51	51.41	73.76	-22.35	32	9
8	5.9	13.74	16	27	27.40	39.22	-11.81	31	15
9	19.8	37.87	8	202	199.73	74.26	125.48	10	2
10	1.6	0.00	32	13	12.25	7.84	4.41	28	-4
11	3.3	0.44	29	21	20.82	18.30	2.51	29	0
12	8.5	10.44	18	87	85.60	41.88	43.72	17	-1
13	8.8	0.68	28	70	69.10	41.39	27.72	22	-6
14	8.4	1.61	25	80	78.55	37.74	40.81	19	-6
15	17.7	16.94	14	221	218.44	75.02	143.42	7	-7
16	8.3	11.66	17	92	89.89	34.97	54.92	16	-1
17	6.0	3.70	22	139	134.01	28.37	105.63	12	-10
18	6.6	15.97	15	47	46.52	34.16	12.35	25	10
19	2.6	1.26	26	22	21.44	15.15	6.29	26	0
20	1.0	0.00	31	14	12.72	6.52	6.20	27	-4
21	5.0	2.02	24	51	49.18	20.85	28.33	21	-3
22	12.8	21.06	13	126	124.16	52.40	71.76	14	1
23	12.8	4.27	21	139	136.84	52.40	84.44	13	-8
24	17.9	21.06	12	200	197.73	73.50	124.24	11	-1
25	43.9	38.47	7	450	447.95	177.20	270.75	2	-5
26	29.7	75.20	5	303	301.02	121.56	179.46	5	0
27	24.2	85.84	3	328	325.03	101.22	223.82	4	1
28	2.3	0.26	30	84	74.90	9.62	65.28	15	-15
29	2.4	0.77	27	36	32.85	9.82	23.04	23	-4
30	23.6	67.56	6	222	219.78	82.85	136.93	8	2
31	45.4	7.42	19	405	402.74	150.06	252.69	3	-16

Notes:
1) PFI = the Potential for Improvement is defined as the difference between the EB estimate (observed collisions) and the expected or normal collisions (from the prediction model).
2) Difference in ranks between RSRI and potential for improvement.

Under a null hypothesis of no correlation, the ordered data pairs are randomly matched and thus the sampling distribution of (ρ_s) has a mean of zero and the standard deviation (σ_s) as given in equation 4.10.

$$\sigma_s = \frac{1}{\sqrt{(n-1)}} \qquad (4.10)$$

Since this sampling distribution can be approximated with a normal distribution even for relatively small values of n, it is possible to test the null hypothesis on the statistic given in equation 4.11. This value can be compared to a critical z-value of 2.33 representing the 99% level of significance.

$$z = \rho_s \sqrt{(n-1)} \qquad (4.11)$$

The results from the correlation analysis are summarized below in Table 4.12. The results indicate that the ranking from the subjective road safety risk index (RSRI) and the objective safety measure (the potential for improvement based on the difference between the existing and expected collision frequencies) do agree at the 99% level of significance. The results that are produced by the Spearman rank-correlation coefficient provide evidence that the risk index correlates well with the potential for improvement based on the historical collision frequency that have occurred on the corridor. A value 0.700 was obtained for the Spearman rank-correlation coefficient and this value is considered adequate to validate the success of the road safety risk index.

Table 4.12: Level of Agreement Between Risk Index and Collision Frequency

Spearman Rank Correlation Coefficient	RSRI compared to Potential for Improvement
N	31
$\Sigma(d)^2$	1488
r_s	0.700
σ_{rs}	0.183
Z	3.834
Significance At 99 % Level (z > 2.33)	**Yes**

By providing definitive guidelines on how to assess the three components of road safety risk (exposure, probability and consequence), the process can be made replicable, with consistent results produced independent of the observer. The statistic kappa (Cohen, 1960), (Fleiss, 1971), (Spring, 1993) was used in the case study to determine the consistency and the reliability of the risk assignment between observers. The level of agreement was considered acceptable thereby supporting the requirement for a replicable RSRI process.

A systematic process was described to determine which road features should be investigated, as well as how each feature should be evaluated during the drive through review. It was not reasonable, nor necessary to list all possible road features associated with the many different road types. Rather, several typical road features associated with rural and urban roads were provided to illustrate the process. This accommodated another objective: that the RSRI process is flexible and can adapt to the needs of many users and differing conditions.

At times, the collection of data can be a cost-prohibitive exercise. Developing a costly data collection process to obtain the road safety risk index would not be considered successful. However, the requisite data for the developed process can be collected without great expense and can be completed before significant and costly decisions are made to address road safety concerns.

The validity of the RSRI was evaluated by comparing the results of the risk index with an objective safety measure defined as the 'potential for improvement' (PFI), based on the difference in the existing and expected collision frequencies. Accurate estimates of the existing and expected collision frequencies were obtained by using a collision prediction model and applying the Empirical Bayes technique. The Spearman's rank correlation coefficient was used to determine the agreement level between the results of the RSRI and the PFI. Homogeneous segments were ranked according to both the RSRI and the PFI, with the results of the Spearman correlation indicating agreement at a 99% significance level.

Due to the quantifiable nature of the RSRI and the validation of the RSRI, the results can be used to support road safety analysis and decision making. In particular, intersection or road segments of high risk can be identified and isolated for road safety improvements. Another opportunity arising from the results of the RSRI is that specific road improvements can be formulated to address specific problems determined when each road feature is investigated separately. For example, locations with a problematic roadside can be identified and mitigative solutions, such as the installation of roadside barrier, can be used to address this specific problem.

It should also be noted that the drive through process allows for the investigation of features that are not normally available through a police collision report form, such as the potential for driver confusion or level of road user hazard. One final benefit associated with the production of the RSRI is that the technique can assist in the formulation of road improvement strategies. Often a site visit is required in formulating road improvement plans, and with the completion of a drive through review, the need to undertake a visit may be reduced or in some cases, eliminated.

The corridor used for the case study was selected in part, because it was the focus of major planning project. With the cooperation from staff from the BC Ministry of Transportation and Highways, the RSRI was critiqued for its usefulness in road safety analysis. The results from the RSRI were used in combination with the collision analysis and a stakeholder consultation process in formulating a safety master plan for the corridor. This safety master plan represented part of the overall upgrading plan for the Trans Canada Highway Corridor. In fact, since the critique and testing of the RSRI in 1998 and due to the ongoing deterioration of collision data for provincial highways, the BC Ministry of Transportation and Highways has requested that a drive through safety review (based on the RSRI process) be completed when highway corridors plans are formulated.

4.7.2 Limitations of the Road Safety Risk Index

One of the fundamental limitations of the road safety risk index is the subjective nature of the process. Any process that relies on a subjective assessment can be susceptible to accuracy problems. Effort has been made to establish specific thresholds for the elements of the RSRI, attempting to make the process quantifiable, but it remains a subjective process and thus the accuracy can be questioned.

Another limitation is that at times, a high-risk roadway feature (or combination of high-risk features) may not result in a high frequency of collisions at the site. Although counter-intuitive, this phenomenon is somewhat common, where a roadway with very poor design characteristics exist, but because a driver can identify the potential risk associated with these problem features, he/she will adapt their driving behavior. This driving behavior generally means that more caution is exercised, thereby resulting in fewer collisions. This limitation is more applicable to drivers who may be unfamiliar with an area or those drivers who may have difficulty in recognizing locations of potential risk.

Another limitation of the RSRI is that it does not provide a sustained opportunity to observe and detect problematic traffic characteristics. Unlike a traffic conflict survey in which observers are stationary for an extended period of time to uncover intersection safety problems, the drive-through safety review is largely limited to an investigation of static road features. This is likely to be more of a problem in an urban area, but can also exist in rural areas where traffic problems can exist and are often unexpected.

5.0 FRAMEWORK FOR PROACTIVE ROAD SAFETY PLANNING

All too often, engineering strategies aimed at improving road safety are reactions to existing problems that are brought to light by collisions which have occurred after the road has been built. Targeting problem locations and developing plans to reduce collision potential is vital and has proven to be very successful. However, transportation professionals should also take a proactive approach that addresses road safety before problems are allowed to emerge.

This chapter addresses an evolving need of how to deal with road safety in a proactive manner. Notable improvements can be made by explicitly addressing safety concerns early in the planning stage. Moreover, the earlier that road safety is considered, the more cost-effectively it can be accommodated. A proactive approach to deliver road safety is intended to complement the more traditional, reactive methods currently in use. Significant progress should be realized once safety professionals who, in addition to fixing existing road problems, can also help to plan and design roads that strive to be problem free.

Although a proactive approach to road safety planning should improve the overall road safety performance, there is currently a poor understanding of how to proactively address road safety. A proactive approach to road safety suffers from three obstacles. Each of these obstacles will be described in greater detail in subsequent sections of this chapter, together with the opportunity to overcome each obstacle. The three obstacles associated with a proactive approach road safety planning include:

1) a lack of opportunity within the traditional transportation planning process to explicitly consider road safety issues,
2) a lack of the necessary methodology and reliable tools to evaluate road safety in a proactive manner, and
3) a lack of a systematic process and framework to explicitly consider road safety issues.

5.1 A Review of Proactive Road Safety Initiatives

5.1.1 Sustainable Road Safety

Although the Netherlands is one of the safest, highly motorized countries in the world, ranking fourth behind the United Kingdom, Sweden and Norway (based on road deaths per inhabitants) (Wegman, 1996), the Dutch Government is still highly committed to improvements in road safety. In 1987, the government of the Netherlands set a series of very optimistic road safety targets, including a 25 percent reduction in the annual number of casualties from 1985 to the year 2000 (Fortuijn, 1992).

Later in 1990, the Dutch government set even more optimistic targets, including a 50 percent reduction in the annual number of fatalities and a drop of 40 percent in annual hospital admissions resulting from motor vehicle collisions by the year 2010 in comparison to the 1986 statistics (Wegman, 1997(1)). It was concluded that the road safety targets set for the year 2010 could not be achieved with traditional approaches to road safety, even if the scope of these traditional approaches were greatly intensified. A new and innovative policy and approach was necessary to increase safety performance to achieve the desired levels.

As a result of the need for a new approach to address road safety, the Dutch government requested the national Road Safety Research Institute (SWOV), to develop an approach to implement and achieve a safer road system. By working in cooperation with the Dutch Ministry of Transport and other road safety institutes, SWOV staff developed a new policy vision for the systematic improvement in road safety performance, called a 'sustainably safe traffic system' or 'sustainable road safety' (Hamelynck, 1994). The starting point for the concept of 'sustainable safety' is to significantly reduce the probability of collisions and to prevent collisions by means of infrastructure design. In addition, when a collision does occur, the process that determines the severity of these incidents should be managed such that serious injury is virtually eliminated (Koornstra, et al., 1990).

Researchers at the SWOV Institute for Road Safety Research concluded that the key to achieve a sustainably safety road system lies in the systematic and consistent application of three safety principles:

1) Rationalize and deploy the functional use of the road network with the objective of preventing the unintended use of a roadway.
2) Ensure the homogeneous use of the road network by preventing large differences in vehicle speed, vehicle operating characteristics, and vehicle travel objectives.
3) Build predictability into the road system to prevent uncertainties among road users thereby improving driver reaction and judgment and the overall behavior of all road users.

The three safety principles listed require that each roadway within a system be evaluated to determine the specific function for that roadway. All roads are built with one major function in mind, referred to by SWOV, as the "travel function". Four unique travel functions are distinguished for roadways (SWOV, 1993):

1) <u>The Flow Function</u>: a roadway designed to allow high-speed traffic, while eliminating conflicts with on-coming and intersecting traffic.
2) <u>The Distribution Function</u>: A road with a high density of at-grade intersections, allowing for the distribution of traffic on the system.
3) <u>The Access Function</u>: Roads where traffic origins and destinations are adjacent to the roadway and traffic is allowed direct access.
4) <u>The Residential Function</u>: A road designed such that the residential function is immediately recognizable; intended to be a shared-use facility.

The concept of a sustainably safe road can be expressed by removing all road function combinations and make each roadway mono-functional, or pure roads (i.e., a pure flow function). Multi-function roads, such as arterial roads, can lead to contradictory design requirements and ultimately, to higher safety risk. Table 5.1 illustrates the risk levels for different types of roads in the Netherlands.

Table 5.1: Injury Rates in the Netherlands by Road Type

Road Type	Speed Limit	Mixed Traffic	Intersecting Traffic	Injury Rates per 10^6 km
Residential areas	30	Yes	Yes	0.20
Urban Street	50	Yes	Yes	0.75
Urban Artery	50 / 70	Yes / no	Yes	1.33
Rural Road	80	Yes / no	Yes	0.64
Express Road	80	No	Yes	0.30
Motor Road	100	No	Yes / no	0.11
Motorway	120	No	No	0.07

Source: The Concept of a Sustainably Safety Road Traffic System (Wegman 1997(1)).

With an understanding of the functional requirements for each roadway category, a set of planning criteria and/or principles have been suggested to develop a sustainably safe traffic system (van Minnen & Slop, 1994). Twelve guiding principles are suggested, and are listed in point form below.

- create residential areas that are as large as possible but compact,
- for any trip, utilize the safest type of road as much as possible,
- make the length of trips as short as possible,
- combine short trips with safe roads,
- prevent driver 'search behavior' for destinations,
- make sure that a road function (type) is clearly recognizable,
- ensure uniformity in road design characteristics,
- prevent conflicts between on-coming traffic,
- prevent conflicts with crossing traffic,
- explore opportunities to separate different transport modes,
- reduce vehicle speeds at locations were conflicts occur, and
- ensure roadside hazards are removed or protected for errant vehicles.

The implementation and evaluation of sustainable road safety in the Netherlands has been realized through several demonstration projects and early results indicate success. It is without doubt, that in the period between launching the concept in 1991 until today, sustainable safety principles have induced new energy into the road safety community. Many stakeholders and road safety professionals have worked together to expand the concept and contribute to the implementation and evaluation. The debate on sustainable safety, which continues today, is on how to expand the concept and realize a safer road system, a system that can achieve the optimistic goals set many years ago.

5.1.2 Planning for Mobility and Safety

Within the context of transportation planning, it is important to present the impact and relationship between mobility and safety. Mobility is the prerequisite for collisions, understanding that a few collisions occur when there is low traffic volume and many collisions occur when there is high traffic volume. As such, road planning involves the trade-off between two competing values: mobility and safety. Mobility is valued for what it permits us to obtain; our economic and social goals while safety is valued for what it permits us to avoid; the human and economic costs associated with the occurrence of traffic collisions (Campbell, 1992).

An increase in mobility normally involves an increase in traffic volumes or travel speed resulting in a corresponding increase in the collision risk due to increased exposure (volume) or consequence (speed). Conversely, an increase in safety often comes at the expense of mobility by reducing travel speeds or limiting traffic volume. Another contrast between mobility and safety is the recognition or perception in the 'supply' of each. Road users can easily perceive a change in mobility through increased delay or higher travel speeds. Conversely, road users have considerable difficulty in recognizing a reduction in the road safety performance level provided, such as an increase in a road design standard (i.e., wider travel lanes).

Recognizing this conflict, it has been stated (Ogden, 1996) that collision losses can be controlled or reduced by managing mobility and ensuring that safety is appropriately accommodated. In attempting to accommodate and resolve the conflict between mobility and safety, Haight (Haight, 1992) suggests that there is little value in recommending solutions that contradict normal human behavior or lack acceptable reality. Rather, it is useful to investigate mechanisms that could be deployed to achieve an ideal transportation system, a system which included the following elements:

- Provide infrastructure to support traffic demands and attempt to isolate different road users (i.e., separate trucks from passenger vehicles).
- Encourage the use of transit systems by making the system quick, cheap and convenient.
- Design a compact urban form that allows for walking and cycling trips to replace work and on-work automobile trips.
- Encourage alternate modes of transportation (rail, air, etc.) for lengthier travel requirements.
- Impose positive regulation that controls high-risk system users, but provide suitable and attractive alternatives.
- Employ intelligent transportation systems to improve the safety and mobility for all road users.
- Implement these initiatives in a cost-effective manner, by examining the benefits versus the costs and make decisions accordingly.

In examining the mechanisms that have been suggested to achieve the ideal transportation system, it can be noticed that many of these recommendations are currently in existence. Although currently in existence, many of these mechanisms do not deliver the safety and mobility performance levels that are desired. Therefore, it can be concluded that many current initiatives can improve the conflict between safety and mobility, however, the problem seems more a matter of how to improve on the delivery of these initiatives and making them more effective.

5.1.3 Proactive Road Safety Auditing

One fairly common proactive road safety initiative is the road safety audit. A road safety audit is a tool that can be used by safety professionals to proactively ensure that road safety needs are adequately addressed before a road is opened to the motoring public. A road safety audit is defined as follows:

> *"A formal examination of an existing or future road project, in which an independent and qualified examiner reports on the project's collision potential and safety performance" (Austroads, 1994).*

There are two basic objectives of a road safety audit. Firstly, the audit teams should identify the potential for road safety problems, both for motorists as well as for all other system users. Secondly, the audit team should ensure that all measures that have the potential to reduce or eliminate the safety problems are adequately considered.

From these objectives, several beneficial outcomes are expected from a road safety audit. First, the frequency and/or severity of collisions can be reduced. Second, safety concerns become more important and given greater prominence in the minds of road planners, designers and traffic engineers. Third, the need for subsequent rehabilitation work to 'fix' the problems can be greatly reduced. Finally, the total cost of a project to the community, including the trauma, cost and disruption caused by collisions can be minimized (Austroads, 1994).

The value of a road safety audit is evident even though the inclusion of a road safety audit represents another component of the planning and design stage of a project. The cost of conducting a road safety audit and the costs associated with the improvements resulting from the audit recommendations are significantly less than the cost of remedial treatments once the work is constructed. In other words, it is easier to change the pencil lines on a proposed plan than to alter a location once the asphalt and concrete has been pored and set in place. This represents the proactive advantage of the road safety audit process.

5.2 Delivering Proactive Road Safety Planning

The introduction to this chapter listed three obstacles associated with proactive road safety planning. These obstacles included a lack of an **opportunity** to explicitly consider road safety issues, a lack of **methodology and tools** necessary to evaluate road safety needs, and a lack of a systematic **process or framework** for planners to consider road safety issues. The following three sections of this thesis will describe each of these obstacles in detail and the associated improvement proposed to overcome the specific obstacle. The concepts presented in the literature review will be used as a basis for the development of the systematic framework for proactive road safety planning.

5.3 Opportunity for Proactive Road Safety Planning

5.3.1 Obstacle to Overcome

It has been stated that significant improvement to the safety performance of a road is not automatically achieved through a typical planning and design project (TRB, 1987). Historically, the road planning process rarely allows planners to consider the impacts of planning decisions on road safety. Instead, planners think that specific safety issues will be addressed in the design stages. At the design stage, road designers rarely explicitly consider road safety objectives, thinking instead that road safety requirements will be addressed implicitly through the application of road design standards. Therefore, the first step in developing a systematic framework for proactive road safety planning is to understand the opportunities to provide safety input into the process.

In reviewing the literature regarding the traditional approaches to road and highway planning, it becomes evident that explicit consideration of road safety issues and concerns is sadly lacking. Stepping through the traditional process shown in Figure 5.1, safety is rarely, if ever, explicitly considered. For example, a measure of road safety performance may be listed as a goal of an organization, but often this measure of safety is ambiguous or loosely defined as to "improve" or "maintain" road safety performance.

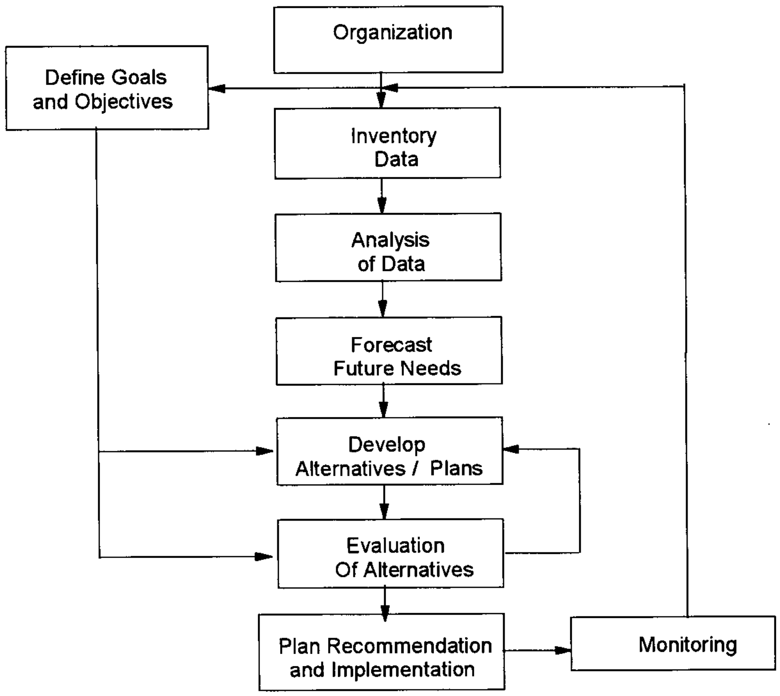

Figure 5.1: Major Steps in a Transportation Planning Process (ITE, 1982)

The planning process associated with data inventory, analysis and forecasting stages (Figure 5.1) normally only involve the presentation of an aggregate safety statistic that often is not too meaningful to the planning process. For example, planners developing a roadway to operate as an urban freeway may specify a target safety performance measure of 0.8 collisions per million vehicle miles. This objective is based the average safety performance of on similar roadways, but is meaningless in the development of safe planning options.

In the option generation and evaluation stages, road planners have difficulty in assessing the impact on safety performance between options and as such, safety considerations are often ignored. Options are usually generated based on mobility needs (minimizing travel time), avoiding environmentally sensitive areas, the ease of construction, or other tangible objectives that are more easily assessed. Specific consideration of important safety issues often does not surface within the option generation stage of planning.

5.3.2 Proposed Improvement

The evolution of a roadway from before a road exists through the planning, design, construction and operation is presented schematically in Figure 5.2. The opportunity to provide safety inputs into the planning process is also presented in Figure 5.2. The opportunity to provide safety input into the process is available from the start of the process (when no road exists) through to the design stage. At the design stage, there is also an opportunity to address road safety in a proactive manner. After design and construction, the safety inputs are comprised of reactive actions, responding to emerging problems on the newly constructed and operating facility.

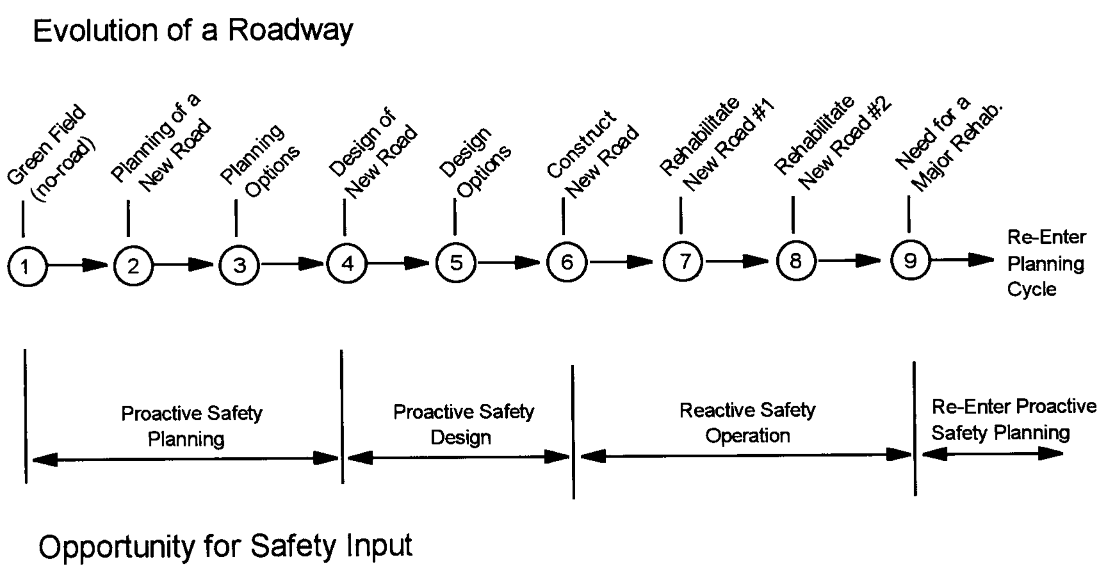

Figure 5.2 Evolution of a Road and Opportunity for Safety Input

The first opportunity to provide explicit safety influence within the planning process is by influencing the planning decisions used to develop potential solution options (number 2 in Figure 5.2). There are several guiding principles that will be described in a subsequent section (Section 5.5) on the process and framework that will enable decisions to be influenced by safety requirements. The value of this opportunity is that safety is "built-in" as each planning option is formulated.

Another opportunity to influence the road safety performance within the planning stages is to evaluate the planning options that are generated by the planning team (number 3 in Figure 5.2). This opportunity is characterized by an 'auditing' or 'checking' function that ensures that safety performance is optimized. This provides a valuable input to the process and can result in the modification of proposed planning options. The methodology and framework for this proactive road safety function is described further in Section 5.6.

5.4 Methodology to Evaluate Road Safety in a Proactive Manner

5.4.1 Obstacle to Overcome

There is a lack of the necessary methodology and tools to evaluate road safety in a proactive manner. This obstacle can be characterized by a lack of a credible and consistent method to estimate the impact on road safety performance arising from a planned improvement. This may be due in part, to a lack of guidance for practitioners and inadequate knowledge in terms of how to quantify or estimate the road safety performance. For road safety decisions to be made early in the planning or design stage, it is important to understand the impact of an action on safety performance. Unfortunately, a reliable and systematic approach to evaluate the impact of road improvements is not currently in use by planners and as such, the ability to comment on the pre-implementation success of many road safety initiatives is inhibited.

5.4.2 Proposed Improvement

In formulating a methodology to assist in proactive road safety planning, it was necessary to consider the fundamental elements that describe road safety in a quantifiable manner. As described previously, many road safety-engineering researchers (Hadden, 1980, Hauer, 1982, and Koornstra, 1992, Navin, 1997) isolated three elements to define safety risk. Recall that the three fundamental elements to describe risk include the **exposure** to hazards, the **probability** of encountering a hazard and the **consequence** if the hazards are encountered. The relationship to describe road safety risk was presented in Chapter 4.

Understanding the three fundamental elements that are used to quantify road safety risk, it is important to identify the specific elements relevant to a road planning exercise. These elements will form the basis to establish the systematic process and framework for safety inputs into the planning of a new road.

5.5 Systematic Process and Framework for Road Safety Planning

5.5.1 Obstacle to Overcome

Currently, there is a lack of a systematic process and the necessary framework to explicitly consider road safety issues for proactive road safety planning. Given the opportunities to provide input into the process and the proposed methodology to quantify safety impacts of planning decisions (as described previously), it is necessary to develop a systematic framework to assist planners to effectively address road safety while formulating planning alternatives.

5.5.2 Proposed Improvement

In describing the proposed framework for proactive road safety planning, the specific elements relevant to a road planning exercise are categorized according the three fundamental elements used to quantify road safety risk (exposure, probability and consequence). Several guiding principles are established to facilitate the consideration of proactive safety planning associated with each specific element. In addition, a means to measure or quantify the relative impact on road safety is recommended for each guiding principle.

5.5.2.1 Planning Decisions Affecting Exposure (Road Safety Risk)

In order to reduce road safety risk, a road user's exposure to the risk should be minimized. There are several measures used to quantify exposure; the most common being traffic volume, recorded in vehicles per unit of time. In order to evaluate decisions that affect exposure, three specific planning elements have been identified. The three specific elements of exposure include land use shape, road network shape / efficiency, and mode choice. A description of each element and the methodology to evaluate is listed in point form below.

➢ *Land Use Shape:*

Land use should be shaped to minimize the distance between origins and destinations and to reduce the need for travel. Influencing the land use is accomplished by understanding the existing and future traffic demands on the system. The guiding principles for proactive road safety planning include:

1. Attempt to create compact urban form, thereby reducing the travel distance and travel time requirements. Measure the safety impact by summing the products of the traffic volume and the travel distance between origins and destinations, attempting to minimize this value while still serving mobility demands.
2. Land use shape can be established to encourage the use of alternative transportation modes. This may involve developing land-use plans to create higher population densities on routes where transit or cycling may be a preferable option or where industrial traffic may have greater access to rail or water transport options. Measure the safety impact by estimating reduced traffic caused by mode shift resulting from land use assignment.
3. Land use plans should be developed to minimize the traffic interaction and exposure between conflicting land use types such as industrial and residential areas. Measure the safety impact by the physical separation and connectivity between the conflicting land use types.
4. Land use controls can be established to restrict commercial development in areas where the traffic from commercial development would be considered a detriment to road safety. Measure the safety impact by the degree and compactness of commercial development, as well as the access control requirements for commercial development.

➢ *Road Network Shape and Efficiency:*

Similar to land use shape, the safety impact of network shape and efficiency relates to the amount of traffic and the travel distance on the network. The distinction is that rather than altering land use assignment, the road network is reviewed to determine the opportunities to minimize the amount or distance of travel. Influencing the network shape is accomplished by understanding the existing and future traffic demands on the system and several guiding principles are established to assist planners consider safety in determining network shape.

1. Address the travel demands by ensuring that efficient routes serve the significant travel movements. Measure the safety impact by summing the product of the traffic volume and the travel distance along all routes. Collision prediction models could also be used to predict the safety performance for different types and classifications of roadways (greater detail of collision prediction models is provided in Chapter 6).
2. Network and routing options may be developed to minimize the amount of traffic that may utilize a facility or to encourage alternate modes of travel. The safety impact can be measured by determining the increased difficulty in reaching destinations (increased delay, distance, cost) or estimating the potential increase in rider-ship on alternate modes.

➢ ***Mode Choice:***

Perhaps one of the best methods to reduce the exposure parameter in the safety risk function is to encourage and facilitate high occupancy vehicle (HOV) transportation modes such as transit operations, HOV lanes, and light-rail transportation. Several guiding principles have been developed to influence mode choice, attempting to increase HOV usage, thereby decreasing single occupant vehicle usage (SOV), and thus, reducing exposure.

1. Consider the construction of facilities to accommodate HOV modes, thereby providing more efficient and attractive HOV service. The safety impact can be measured by estimating HOV facility usage and the reduction in traffic volume or time delay on the system between SOV and HOV traffic.
2. Provide safe, secure and convenient infrastructure to accommodate non-motorized transportation modes such as pedestrian and cyclists. Measure the safety impact by estimating the usage of the facilities and the corresponding net reduction in motorized traffic on the system.

5.5.2.2. Planning Decisions Affecting Probability (Road Safety Risk)

The second factor that determines the road safety risk is the probability of a system user becoming involved in an incident. There are several specific factors that control the probability of an incident that must be quantified in formulating the framework. Six specific elements of probability are suggested to consider safety in the planning of a roadway.

➢ *Maneuverability:*

Guide the development of planning options to ensure vehicle maneuverability is not constrained. Generally, a system that provides for the ease of vehicle maneuverability is considered safer than a system that is constrained (traffic calming may be an exception to this). An unconstrained system is considered safer since the probability of becoming involved in an incident is reduced by lower traffic density, less vehicle conflict, less delay and less driver frustration.

1. Provide facilities to ensure that the traffic demand is met, ensuring that an adequate level of capacity is available on a system. This includes elements such as the number of lanes, the timing of signals, or the provision for passing lanes. The safety impacts can be measured by conducting a level of service analysis, measuring the delay, speed or traffic density on the system.
2. Explicit attention should be focused at the accommodation of commercial vehicles and the interaction with other vehicles. This includes any roadway feature that may limit a commercial vehicle's maneuverability such as steep grades or tight horizontal curves. Measure the impact by estimating the magnitude of maneuverability restrictions in terms of time delay or level of interference.
3. Attempt to minimize the number and severity of required vehicle movements within the road system. This includes the need for motorists to change lanes, as well as merging and weaving maneuvers. The safety impact is determined by calculating the product of the number of required vehicle maneuvers and the corresponding traffic volume.

➢ *Geometric Design Elements:*

Influence the safety performance of planning options by providing an opportunity at the design stage for generous or favorable geometric design elements. Although the details of many geometric features are not available until the design stage, what can be achieved at the design stage is often pre-determined by the options developed in the planning stage.

1. Favor routing options that offer the least amount of topographic constraints such that obtaining cross-sectional dimensions (lane width, shoulder width, clear zone, etc.) can be easily achieved. The safety impact can be measured by the physical constraints associated with each option.

2. Attempt to develop route options that avoid curvilinear alignments and locations of steep grades. The safety impact can be measured by comparing the frequency of curves and the degree of horizontal / vertical curves between the various options being generated.

➢ *Roadway Functionality:*

Great opportunities exist at the planning stage to ensure that road function is properly assigned, thereby avoiding the unintended use of a roadway and ensuring predictability of the system by the user. This item is derived from the recommendations from the Dutch experience (SWOV, 1996), who state that it is important to ensure road function is homogeneous. The following principles attempt to achieve the desired road function, thereby reducing the probability of a system user becoming involved in a collision.

1. By understanding the travel demands on the system, attempt to match the travel characteristics with the appropriate facility. For example, inter-regional trips should be serviced exclusively by a through-road with limited access. Alternatively, local trips should be confined to roadways that only serve local needs and deviation from this function would result in a time or distance penalty to the trip maker. The safety impact can be measured by estimating the opportunity for unintended use of the desired function of a facility.
2. Attempt to plan the road system to maximize the use of the safest roads in the network, including the highest road function (freeways) and the lowest road function (local). The least safe road forms such as a mixed-use road (access and distribution roads) are necessary but their usage should be minimized. The safety impact can be measured by determining the length of different road types and then calculating the expected collision frequency using collision prediction models developed for the different road categories.
3. Provide consistency in the homogeneity of road character, thereby ensuring the proper use of each roadway. Roads that do not maintain consistent character along the length of the roadway may encourage non-intended trips. The frequency and severity of deviations from consistent road character can be used to measure the safety impact.

➢ *Conflicting Traffic:*

Safety performance can be influenced by attempting to minimize the total number of conflicting-traffic movements. In general, improved safety performance is realized with fewer conflict points, although it is the conflicting traffic volumes that should be evaluated.

1. Minimize the number of conflicting-traffic movements, including the conflict points at intersections and interchanges. Measure the safety impact by summing the total number of conflict points.
2. Collision prediction models can provide a reliable estimate of the safety performance of different facilities. Therefore, to measure the impact on safety, calculate the expected collision frequency at intersections or interchanges by using collision prediction model for the facility under investigation.
3. Gauge the safety implications of each conflict point in terms of the potential for excessive probability or consequence of collision (consequence is included here for convenience). Not all conflict points are 'equivalent' and thus, this issue meant to give greater emphasis to those conflict points that have the potential to be most problematic due to vehicle speed, possible sight-distance restrictions (due to poor alignment or topography) or potential for driver confusion. Safety impacts are determined by identifying the number conflict points that are excessively problematic.

➢ *Roadway Friction:*

Planners should be made aware of the potential for roadway friction and the impact on safety performance. Road friction can occur when the features of a road cause hesitation and uncertainty by the road user, resulting in unnecessarily hasty or hazardous maneuvers. Consider the following road friction issues:

1. Determine the amount of roadway that has confining geometric elements that may increase roadway friction such as sections of curvilinear alignment, areas of severe rock cuts, or any roadway narrowing (i.e., at bridge structures). The number and severity of confining elements creating road friction can measure the safety impact.
2. Gauge the magnitude of road friction caused by traffic elements such as differential vehicle speeds, the presence of on-street parking, and the interaction with alternate modes. Measure the safety impact by estimating the speed differential, the amount of parking or any other feature creating friction, with less friction considered safer.

➢ ***Predictability of the Roadway:***

Guide the planning process to ensure that a roadway conveys a clear message to the driver thereby ensuring predictability. It is important to identify any road feature that may violate driver expectation, thus creating a hazardous situation. As considerable judgment is required, it is impossible to provide guidance for all possible conditions that violate predictability, but some common principles are listed to illustrate this safety consideration.

1. Identify locations where road elements are contrary to driver expectation or are inconsistently applied throughout a corridor / area, such as a left-side exit ramp on a corridor that normally has all right-side exit ramps. Measure the safety impact by determining the number of unpredictable locations.
2. Complex roadway geometry can create confusion and lead to unpredictability within a roadway system. Although it is often difficult, efforts should be made to ensure that planning options are not complicated and consistent with driver expectations. It is difficult to measure the complexity of planning options and thus, this principle is listed to identify locations of complex geometry and to attempt to simplify if possible.

5.5.2.3 Planning Decisions Affecting Consequence (Road Safety Risk)

Consequence is the third factor that determines the road safety risk and relates to the outcome of an incident once it occurs on the system. There are three specific factors that have been identified to measure the consequence of planning options; namely, protecting vulnerable users of the system, reducing speed in areas of high risk, and reducing roadside risk. Each factor is described below with a listing of some guiding principles that are used to influence the planning process.

➢ ***Protecting Vulnerable System Users:***

In the planning of a road system, it is important to consider all users of the system and their corresponding safety requirements. Vulnerable system users, such as pedestrians (including pedestrians with disabilities) and cyclists, should be explicitly considered and roadway facilities should properly accommodate these users.

1. Understand the study area, ensuring that vulnerable user's needs are met and that appropriate and convenient facilities are planned to meet these needs, such as pedestrian crossings, safe routes to schools, and cycling infrastructure. It is difficult to quantify the protection of vulnerable road users, but the safety impact of this guiding principle can be measured qualitatively by the explicit accommodation of vulnerable user's needs.

➢ ***Reduce Speed in High Risk Areas:***

High travel speeds can have a detrimental impact on the consequence on an incident should it occur. Therefore, it is important in the planning process to identify areas where high speed may be a problem and to implement mitigative actions to restrict speed at these locations.

1. Identify locations where excessive speed may result in severe damage or injury should an incident occur. This includes locations where roadway character may not accommodate high speeds (i.e., a sharp curve at the end of a tangent section). The safety impact may be measured by the number of the locations where excessive speed is considered to be problematic and by multiplying by the affected traffic volumes at these locations.
2. Identify locations where excessive speed may result in a higher likelihood of becoming involved in a collision. This includes locations with high-speed differential, curves requiring speed warnings, sight distance restrictions, or at-grade intersections or crossings. The road safety impact may be measured by the expected difference in vehicle operating speeds between conflicting traffic or by the frequency and magnitude of necessary reductions in speed (of the affected traffic volume).

➢ ***Roadside:***

The nature of a roadside environment will govern the consequences of an incident involving an errant vehicle leaving the roadway. Therefore, the roadside environment is an important consideration in the planning of a roadway within a rural environment, but it should also be considered within an urban setting. Several guiding principles are listed below to assess the safety consequence of roadside areas and to influence road planning.

1. Favor planning options that allow for the easy accommodation of roadside clear-zone standards. These planning options, characterized by few topographical constraints, should be favored over those options with severe constraints. The safety impact can be measured by the amount of cut and fill associated with the various planning options.
2. Place a greater safety benefit on those planning options that have gentler horizontal and vertical alignment. Better roadway alignment will affect the probability of an off-road incident, and the consequence since it impacts the encroachment angle and thus, the speed into the roadside area. Measure the safety impact by favoring those options with the less horizontal and vertical curvature.
3. Investigate the potential of other factors that may contribute to a roadside encroachment. Many factors may contribute to an encroachment, ranging from the likelihood of animals on the roadway (a need to determine animal migratory patterns), to the opportunity for ice to form on the roadway (occurring at higher elevations or as a result of roadway shading). The road safety impact can be measured by qualitatively assessing the potential for roadside encroachment and ensuring that roadside areas are designed to be forgiving.
4. Study the roadside area to identify hazards that cannot be removed and thus, must be shielded to protect the occupants of an errant vehicle. The number of hazards requiring physical protection and the ease in which these hazards can be protected should determined to quantify the safety impact and thus, be used to influence the planning options.

5.5.2.4 Summary

Three components were used to define and quantify road safety risk, namely exposure, probability and consequence. Under each component, were a number of specific elements with several guiding principles formulated to explicitly consider road safety in the planning process. These principles are summarized in Table 5.3 and provide the framework for the first opportunity to proactively influence decisions in the planning process. The process and framework to support the second opportunity to proactively influence planning decisions is described in Section 5.6.

Table 5.2 Summary of Guiding Principle to Influence Road Planning

Exposure		
1.	Land Use	1. Sum the product of traffic volume and distance between O-D pairs.
		2. Estimate reduced traffic caused by mode shift due to land use.
		3. Quantify separation and connectivity between conflicting land use types.
		4. Degree / compactness of commercial development; access control.
2.	Network Shape	1. Sum volume x distance on each route or use collision prediction model.
		2. Discourage travel by increased delay, distance or cost; promote HOV.
3.	Mode Choice	1. Promote HOV facilities; estimate reduced traffic caused by mode shift.
		2. Provide facilities for non-motorized travel; estimate reduced traffic.
Probability		
1.	Maneuverability	1. Conduct level of service analysis to measure system performance.
		2. Estimate maneuverability restrictions in terms of delay or interference.
		3. Sum the product of vehicle maneuvers and the traffic volume.
2.	Geometric Design	1. Qualitative assessment of the magnitude of topographic constraints.
		2. Determine the frequency and degree of horizontal and vertical curves.
3.	Functionality	1. Estimate the unintended use of the desired function of each facility.
		2. Use collision prediction models to estimate safety of different roadways.
		3. Identify number / severity of deviations from consistent road character.
4.	Conflicts	1. Measure safety impact by the total number of conflict points.
		2. Use collision prediction models to estimate safety of different facilities.
		3. Identify the number of conflict points that are excessively problematic.
5.	Road Friction	1. Determine the number and severity of confining geometric elements.
		2. Estimate / quantify the traffic elements causing friction (parking, etc.).
6.	Road Predictability	1. Use a qualitative assessment of the number of unpredictable locations.
		2. Identify locations of complex geometric design and attempt to simplify.
Consequence		
1.	Vulnerable Users	1. Qualitatively assess the accommodation of vulnerable system users.
2.	Reduce Speed	1. Determine where speed is a problem and multiply by affected volume.
		2. Calculate the speed differential and magnitude of speed reductions.
3.	Roadside	1. Estimate the cut and fill as a surrogate for topographic constraints.
		2. Determine the frequency and degree of horizontal and vertical curves.
		3. Assess factors contributing to the potential for roadside encroachment.
		4. Identify roadside locations that require protection for errant vehicles.

5.6 Proactive Road Safety Planning in the Post Planning Stage

The output from the planning stage (number 3 in Figure 5.2) is the development of a series of planning options that achieve, in varying degrees, the objectives set out at the outset of the planning project. There are two opportunities to influence the decisions in the post-planning stage, thereby assisting to select the preferred plan. However, the post-planning opportunities suffer some practical obstacles.

5.6.1 Obstacle to Overcome

In the assessment of options generated in the road planning process, it is rare that safety performance is explicitly consideration. Even if safety performance is considered in the determination of the optimal plan, the evaluation of safety is often ineffective in distinguishing between options. Often a simple, aggregate collision rate, based on average operating characteristics of similar roadways is applied to each option. While this approach may provide some general insight at a system-wide level, it does little to quantify the facility-level impact of variations to road and traffic characteristics. For example, some specific elements that affect safety performance but are not included are the purpose of the facility (i.e., general-purpose versus HOV traffic), the level of congestion, the travel speeds, and cross-sectional elements (i.e., the number of lanes, shoulder width, etc.).

5.6.2 Proposed Improvement

5.6.2.1 Selecting the Optimal Planning Alternative

In the post-planning stage, there are two distinct opportunities to influence safety performance in a proactive manner. The first opportunity is a process that reviews the project objectives, sometimes referred to as a multiple-accounts evaluation (MAE) process. The MAE process evaluates competing options from the perspective of a number of 'accounts' or criteria depending on the planning objectives of the road authority. These could include financial considerations, serving customer needs (traffic and safety operation), environmental protection, promoting urban development, and so on. The process allows for the altering of proposed planning alternatives to improve the attainment of project objectives.

In order to improve the safety inputs to the MAE process, it is suggested that collision prediction models be used to evaluate safety impacts of planning decisions rather than applying an aggregated average collision rate to reflect the 'expected' performance of a planned improvement. Valid collision prediction models offer superior predictive capability and will increase the confidence and reliability of the safety estimate. In addition, the output from a collision prediction model facilitates the economic assessment of planning alternatives with respect to safety performance by allowing a cost of collisions to be associated with each planning alternative. Therefore, a meaningful comparison can be made between options due to the quantification of safety performance and as a result, the preferred planning alternative can be selected.

Some collision prediction models are available for the various road types and features, but a comprehensive suite of local models do not currently exist. Until local models are fully developed, prediction models from other jurisdictions may be used but it must stressed, that these models may not reflect local conditions accurately and may ultimately jeopardize the accuracy of the results. Collision prediction models are the subject of Chapter 6 of this thesis and these issues will be explained further.

Another suggested improvement to the current MAE process is to utilize surrogate safety indicators to compare the relative safety performance between options. Rather than using an aggregate safety measure such as the average collision rate to compare the two facilities, each option can be reviewed in detail and relevant safety indicators can be established. The safety considerations should be isolated from other MAE considerations, thus making safety more prominent in the MAE process. The safety indicators can be based on the guiding principles used in formulating the planning solutions, such as the level of conflicting traffic, the level of maneuverability, and so on. This facilitates a qualitative assessment of planning options and also be used in a relative manner to select the best planning alternative.

5.6.2.2 Auditing the Preferred Planning Alternative

The second opportunity to influence safety within the planning stages is to conduct a road safety audit of the preferred planning option(s). Road safety audits were described earlier in this chapter and the recommended practice follows the work completed by others (Austroads, 1994, Hamilton, 1996). It should be noted that if all of the safety processes were given appropriate attention during the planning process, then this final step of auditing the optimal plan may not yield many improvement recommendations. However, it is considered important that a "fresh set of eyes", or someone that is independent from the planning process reviews the plans to ensure that the plan is safe.

The first step in the process is for the principal road safety auditor to become familiar with the planning option(s). Ideally, a meeting between the planners and the auditors is beneficial to understand the scope, function, land use, and environmental constraints / issues associated with the project. Secondly, the auditor receives all the necessary information from the planning team to conduct the audit including planning criteria, information on road classification, traffic data, road design features, level of service, alternate modes and so on. Satellite or aerial photographs of the site are often very useful to the audit team. The third step involves assembling the necessary expertise for the audit team and then conducting the audit.

Once the road safety audit is complete the auditors prepare a report detailing safety concerns and present the report to the planning team and project owner. The planning team is responsible to consider the auditors recommendations and to formally respond to the auditors on what action, if any, can be taken and the reasons for not accepting or achieving the auditor's recommendations.

Once the planning team prepares a response concerning the auditor's report, the preferred planning option is ready to move into the design stages.

5.7 Summary of the Elements for the Planning Framework

This section is simply a summary of the elements for the proposed framework for proactive road safety planning. The different elements associated with both the planning stage and the post-planning stages are represented schematically in Figure 5.3.

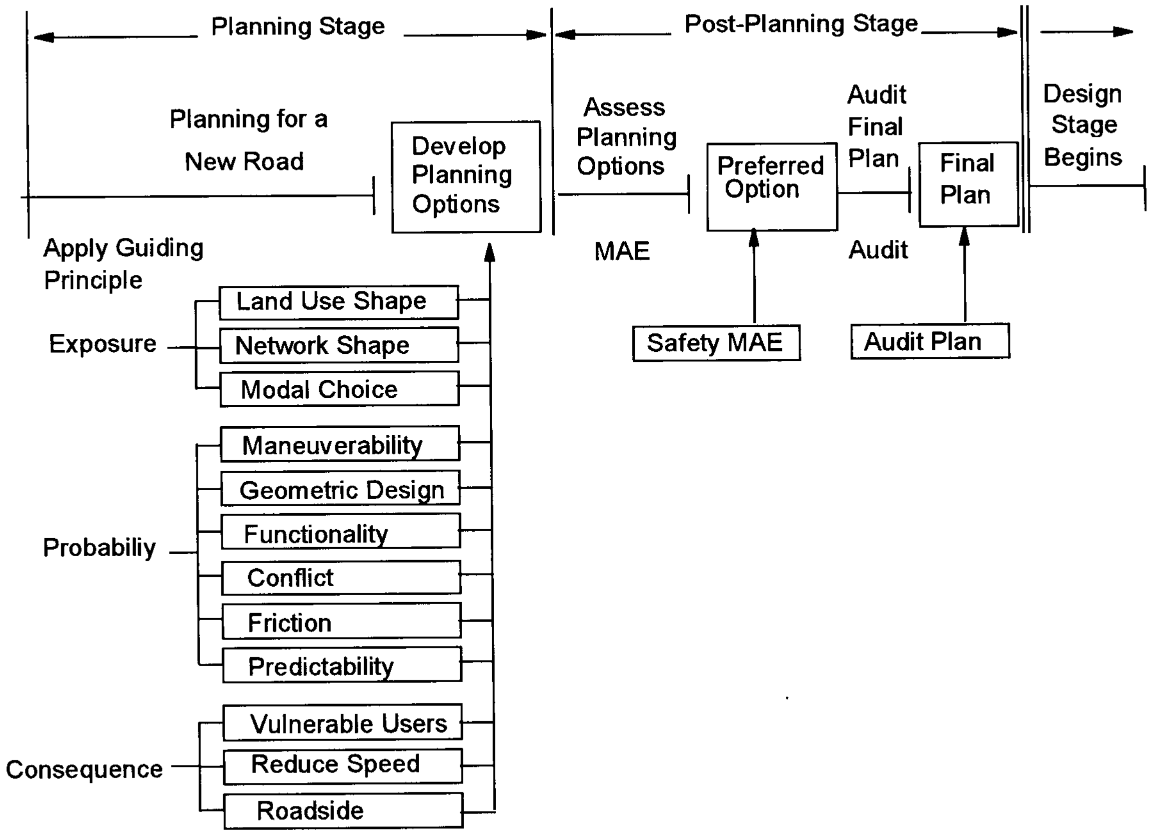

Figure 5.3: Proposed Framework for Proactive Road Safety Planning

The objective of the proposed framework for proactive road safety planning was to facilitate the explicit consideration of safety issues into the current road planning processes. It is anticipated that significant progress will be realized once safety professionals can shift their focus from fixing existing road problems, to helping plan roads that attempt to be problem free. The net result should be a safer road system.

5.8 Application of the Framework for Proactive Road Safety Planning

In order to test the framework and process for proactive road safety planning, a case study will be conducted using an actual highway-planning project located in the Lower Mainland of British Columbia. The intention of this exercise is to test the suitability and validity of the recommended framework and procedures, with the goal of demonstrating the approach.

5.8.1 Project Description

The Ministry of Transportation and Highways (MoTH) is responsible for planning provincial highway corridors. One project currently under review is Route 1, the Trans Canada Highway, from the Brunette Interchange to the east abutment of the Port Mann Bridge, referred to as the Cape Horn Area Network Study. The area is located east of Vancouver and the highway corridor serves as a divider between the municipalities of Coquitlam, New Westminster and Surrey.

The Cape Horn Interchange is a focal point for traffic within the Lower Mainland area of British Columbia. The interaction with the Port Mann Bridge, as well as its role in connecting Highway 7 to the Trans Canada Highway, make the Cape Horn Interchange one of the key transportation links for regional and provincial travel in the Lower Mainland.

As a result of it's high priority, the Cape Horn Interchange is perhaps one of the most congested areas in the province. In fact, under congested conditions, traffic queues from Highway 1 extend many kilometers over the Brunette and Cape Horn interchanges, backing up to Route 7 (an adjacent east-west route). The need to connect Route 7, and other high-priority roads such as United Boulevard, and the Mary Hill Bypass, result in a complicated and unconventional interchange layout that has many weaving sections and connecting roads. These conditions result in poor safety performance in the study area. Therefore, MoTH has initiated a planning study to identify transportation requirements, planning options and a strategy for implementation.

The goal of the planning study is to investigate and evaluate the Cape Horn Area Network in the context of the other planning objectives for the area as defined in major regional planning studies including the Livable Region Strategic Plan and the Lower Mainland Highway System Report. The project is a 'Route Study' (Lisman and Stevens, 1991), where single line sketches are developed at a 1:5000 scale to address alignment issues. Short and long-term options for multi-modal transportation requirements are also determined, based on the attainment of provincial and regional objectives. These options address congestion and safety problems related to the Cape Horn Interchange and the Port Mann Bridge operation. The planning study is also to include the development of alternatives for the Port Mann Bridge and will include the anticipated options related to the construction of a new bridge or the twining of the existing bridge.

The study area is located north of the Fraser River and encompasses Highway 7 (the Lougheed Highway) and the Trans Canada Highway. It also includes the major arterial connections between Brunette Avenue in Coquitlam and United Boulevard, as well as the Mary Hill Bypass to the east. The Cape Horn Interchange is located on the Trans Canada Highway, which acts as one of the most critical transportation links in the Lower Mainland, serving commuter, commercial, and recreational trips for both local and regional traffic. The Cape Horn Area Network planning study area is shown schematically in Figure 5.4 and an aerial photo of the site is shown in Figure 5.5.

It is fortunate that during the course of this research project that the Ministry of Transportation and Highways made considerable progress on this planning study. As such, a wealth of background information and planning reports were available at the various stages of the planning process. In fact, some of the safety planning principles and concepts recommended herein, have been considered in the planning process for this project and it was possible to be involved in an advisory capacity with respect to road safety issues during the planning process.

5.8.2 Developing Safe Planning Options

The Ministry retained a local consultant to develop some planning options, considering all of the Ministry's objectives, one of which is to ensure acceptable road safety performance. Ideally, a safety expert would be involved with the planners to ensure that the options are developed with safety needs explicitly considered by applying the guiding principles for road safety planning. Unfortunately, it was not possible to be part of the planning team and for this demonstration, it will be completed after the planning options were developed. For this case study, it was assumed that the starting point was a 'blank-sheet' and that an improvement option would be developed based solely on the application of the guiding principles for road safety planning.

The nature of this particular case study does not allow for a meaningful application of all of the guiding principles. Some of the guiding principles cannot be effectively applied and when this is the case, the reasons for non-application will be stated. This may seem like a limitation of the case study, but not really as it reflects a real-world deployment and it recognizes that not all of the guiding principles must be used for each planning study.

5.8.2.1 Application of Guiding Principles (Exposure):

The first three parameters relate to the exposure component of the road safety risk function and include land use shape, network shape, and mode choice. In assessing these principles, it is necessary to understand the traffic demand (existing and future) on the system and the potential routing options. However for this case study, applying some of these guiding principles is difficult for the following reasons:

1) the study area is fully developed and land use changes are unlikely,
2) the connecting network is fully developed and unlikely to change,
3) the study area is small, resulting in few route options and,
4) the topographic constraints also limit the route options available.

As indicated, the **land use shape** is fully developed and changes are unlikely. However, a mixture of commercial and industrial land use designations do exist in the central area of the Cape Horn Interchange. This land use designation is considered inappropriate and does create some mobility and safety concerns. The concerns relate to the mixture of *local* traffic generated by these commercial developments, mixed with *industrial* and *regional-through* traffic, maneuvering within the interchange area. In planning improvements, efforts should be made to isolate these commercial developments from access to the through roads.

In investigating the **network shape**, it is clear that due to the small study area and the limited route options, the product of the traffic volume and the distance between origin-destination pairs is not revealing. However, the use of collision prediction models can provide a quantifiable estimate of safety performance. For example, a planning decision must be made concerning the configuration of the collector road connections onto United Boulevard. A conventional solution would suggest that a typical four-leg intersection would accommodate the necessary movements, but two staggered T-type intersections could also serve the required traffic demand and achieve safety benefits as quantified by the prediction model.

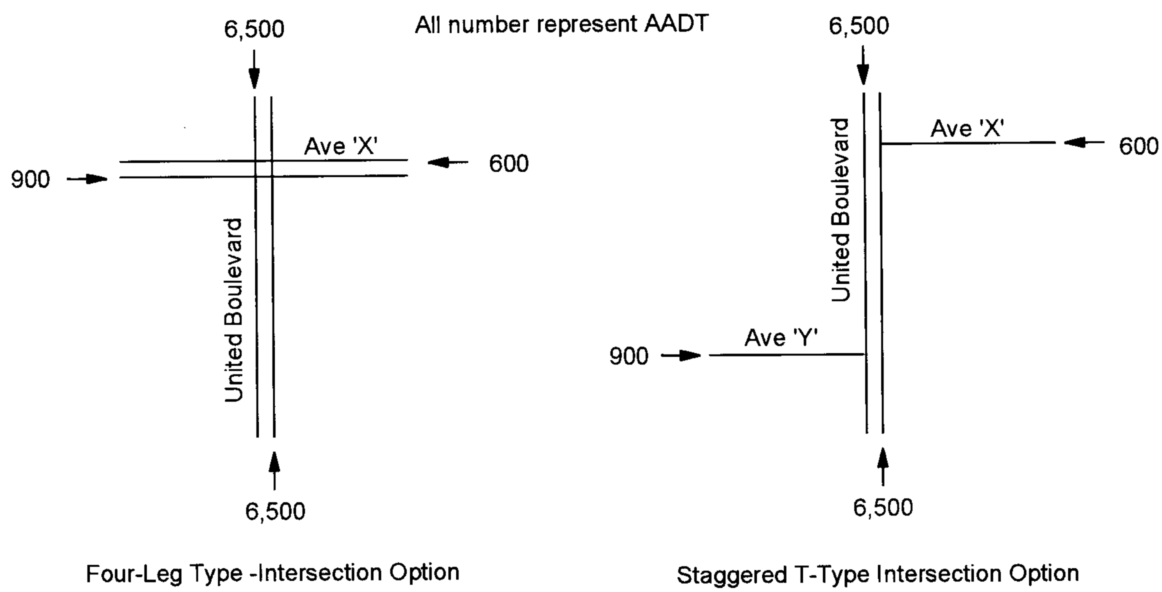

Figure 5.6: Network Shape Planning Decision: 4-Way versus T-Type Intersection

Two collision prediction models (CPMs) were developed by UBC (Sayed, 1998) using data from similar intersection types in British Columbia. The models were tested and were proven to be statistically reliable and are given as follows:

Four-Way: $\text{Acc.}_{freq} = 1.6947 \times (\text{AADT}_{major})^{0.4099} \times (\text{AADT}_{minor})^{0.7065}$

T-Type: $\text{Acc.}_{freq} = 0.9333 \times (\text{AADT}_{major})^{0.4531} \times (\text{AADT}_{minor})^{0.5856}$

where: Acc._{freq} is the expected collision frequency (accident/year)
AADT_{major} is the average annual daily traffic on the major road (1,000s)
AADT_{minor} is the average annual daily traffic on the minor road (1,000s)

By calculating the expected collision frequency, it can be determined that the staggered T-type intersections are safer by an expected 1.5 collisions (6.5 – 5.0 = 1.5) per year. This illustrates the usefulness of CPMs in planning decisions. Ultimately, a cost could be attached to this 1.5 collisions per year and amortized over the life of the facility to determine the economic benefit of this alternative.

Four Way: $\text{Acc.}_{freq} = 1.6947 \times (13)^{0.4099} \times (1.5)^{0.7065}$
$\text{Acc.}_{freq} = 6.5$ collisions / year

T-Type: $\text{Acc.}_{freq} = 0.9333 \times (13)^{0.4531} \times \{(0.6)^{0.5856} + (0.9)^{0.5856}\}$
$\text{Acc.}_{freq} = 5.0$ collisions / year

The one guiding principle related to exposure that can be evaluated, is the opportunity to encourage **mode shift**. Currently, an HOV facility exists on the Trans Canada Highway portion of the study area and this initiative could be expanded to the adjacent routes. The travel-time savings will govern the amount of traffic reduced by a shift from SOV to HOV. Transit operations do not currently exist on the Trans Canada Highway (TCH), but BC Transit should be approached and encouraged to use the corridor for transit service. Currently, the TCH does not allow cyclists to use the highway, however all routes should attempt to accommodate cycling needs and develop facilities accordingly (Interim, 1996).

5.8.2.2 Application of Guiding Principles (Probability):

There are six elements associated with the probability of road safety risk. The first element of probability is **maneuverability**, with the first guiding principle suggesting that level of service (LOS) analysis should be completed to determine the system efficiency, with a better LOS generally reflecting a safer condition (Zhou and Sisiopiku, 1996, Yu, 1972). The LOS calculation is based on Highway Capacity Manual methodology (TRB, 1985), where service levels range from 'A' (the best) to 'F' (the worst). The LOS for a freeway section is based on an average running speed and traffic density.

The LOS for the study area is provided in Table 5.3. An improved level of service is associated with greater road system capacity, and generally, improved safety performance. Thus, it is important to urge planners to achieve the greatest system capacity, although it must be understood that there is a cost to expanded infrastructure (a principle constraint in most planning projects).

Table 5.3: Level of Service Analysis for the Study Area

Roadway Section	**Eastbound**			**Westbound**		
	1998	2021		1998	2021	
Trans Canada Highway	6 Lanes	8 Lanes	10 Lanes	6 Lanes	8 Lanes	10 Lanes
Freeway Section	F	D	B	F	D	B
Cape Horn On – Ramp	F	D	B	D	D	B
Cape Horn Off – Ramp	D	D	C	E	D	C
Lougheed Highway	4 Lanes	6 Lanes	8 Lanes	4 lanes	6 Lanes	8 Lanes
Mid-block Section	F	C	A	F	C	A
Cape Horn On – Ramp	N/a	N/a	N/a	D	D	N/a
Cape Horn Off – Ramp	E	D	C	F	D	B
Mary Hill Bypass	4 Lanes	4 Lanes	6 Lanes	4 Lanes	4 Lanes	6 Lanes
Mid-block Section	C	C	B	C	C	B
Intersections	F	D	B	F	D	B
United Boulevard	4 Lanes	4 Lanes	6 Lanes	4 Lanes	4 Lanes	6 Lanes
Mid-block Section	C	C	A	C	C	A
Intersections	F	D	B	F	D	B

BC MOTH: Based on Cape Horn Area Network Planning Study – Planning Criteria.

The second element associated with the probability in road safety risk is **Geometric Design**, which can be influenced at the planning stage to ensure road safety performance. In formulating planning solutions based on the Route Study criteria consisting (i.e., single line sketches), effort is made to avoid difficult topographic constraints and to minimize the horizontal and vertical curvature.

In developing a planning option for this case study, an attempt was made to make the geometry as generous as possible given the exiting constraints on the network. For example, constraints included the locations of the Frazer River, the TCH, and the Lougheed Highway, which were not going to change. It should be noted that attempting to accommodate all the necessary movements while providing generous geometric alignment proved to be very challenging. In assessing planning options, preference should be given to those alternatives with the least degree of horizontal and vertical curve.

Functionality is the third element to be covered under probability and three guiding principles were recommended. The most useful guiding principle is the application of collision prediction models (CPMs) to assist in decision making. To demonstrate the usefulness of CPMs in defining road function, models from other jurisdictions are used since the requisite models for BC do not currently exist (MTO, 1998). The existing and projected-future traffic volumes and the length of each corridor are required and are given in Table 5.4.

Table 5.4: Traffic Data for the Study Area

Roadway Section	Section Length	AADT		DHV for GP		% Trucks	
		1998	2021	1998	2021	1998	2021
Trans Canada Highway	4.8 km	115,000	180,000	3,800	7,000	2.5%	2.5%
Lougheed Highway	4.2 km	53,000	70,000	2,500	3,300	4%	4%
Mary Hill Bypass	3.7 km	51,000	70,000	2,500	4,500	4%	4%
United Boulevard	5.5 km	13,000	25,000	800	1500	4%	4%

BC MOTH: Based on Cape Horn Area Network Planning Study – Planning Criteria.

Commuters traveling from the east to connect to the Trans Canada Highway have the option of traveling on the Lougheed Highway or the Mary Hill Bypass. Plans are being developed to facilitate these movements and there is a need to determine which route is preferable and the relative safety impact. The first alternative is to maintain the Lougheed Highway at an expressway standard, and the Mary Hill Bypass will continue to function as an arterial roadway. A second alternative is to up-grade the Mary Hill Bypass to that of an expressway standard. The relative impacts of these options are evaluated by using CPMs as follows.

The CPMs for the two facilities are given as follows (MTO, 1998):

Expressway: $\text{Acc.}_{freq} = L \times (0.0009228) \times (AADT)^{0.8116}$

Arterial: $\text{Acc.}_{freq} = L \times (0.0001135) \times (AADT)^{1.0179}$

where: Acc._{freq} is the expected collision frequency (collision/year)
L is the length of roadway (kilometers)
AADT is the average annual daily traffic (vehicles per day)

By referring to the calculations below, this example shows that even though the Mary Hill arterial road is 500 meters shorter in distance, it is less safe than the longer expressway road, by an estimated 2.7 collisions per year (35.7 - 33.2 = 2.7 as shown below). Alternatively, if the Mary Hill Bypass were upgraded from an arterial road to an expressway, the resulting impact would be an expected reduction of 6.6 collisions per year (35.9 – 29.3 = 6.6).

Expressway:
Lougheed Hwy.

$\text{Acc.}_{freq} = 4.2 \times (0.0009228) \times (70000)^{0.8116}$

$\text{Acc.}_{freq} = 33.2$ collisions / year

Arterial:
Mary Hill Bypass

$\text{Acc.}_{freq} = 3.7 \times (0.0001135) \times (70000)^{1.0179}$

$\text{Acc.}_{freq} = 35.9$ collisions / year

Expressway:
Mary Hill Bypass

$\text{Acc.}_{freq} = 3.7 \times (0.0009228) \times (70000)^{0.8116}$

$\text{Acc.}_{freq} = 29.3$ collisions / year

The fourth element associated with the probability in road safety risk is minimizing the number of **conflict points.** In developing an improvement option, it is suggested that each connection within the network (intersections) be studied to determine if the number of conflict points can be reduced. Wherever the conflicting traffic volumes at intersections are excessive, signalization or grade separation should be considered. Again, the relative impact of these planning decisions (intersection versus interchange) can be determined by using collision prediction models if available.

For this case study, there are some significant traffic movements that should be adequately accommodated, including the connections between the Trans Canada Highway and the Lougheed Highway. In formulating a preferred safety plan, effort was made to minimize conflict points by grade separating as many locations as possible. The result is an option that consists of many structures at a significant construction cost. It should be recognized that cost is always a governing factor in developing improvement plans, so the option generated is perhaps too generous and may not be affordable. This emphasizes the need to influence safety during the planning process rather than developing safety solutions independently.

Roadway **friction** and **predictability** are the fifth and sixth elements associated with the probability component of the road safety risk function. It was determined that it is difficult to shape or develop planning options based on minimizing friction and ensuring predictability. Instead, it is suggested that each planning option should be developed based on the other guiding principles and friction and predictability should be evaluated and improved after the option is developed. In other words, it is easier to determine sources of friction (speed differential, parking, confining elements, etc.) and unpredictable locations (those with complex geometry, areas that may cause driver confusion, etc.) and treat them rather than developing planning options to avoid them.

5.8.2.3 Application of Guiding Principles (Consequence)

Consequence is the third factor that determines the road safety risk and it pertains to the outcome of an incident should it occur on the road system. The three elements of consequence include protecting vulnerable system users, reducing speed in areas of high risk, and reducing roadside risk.

Given that the case study represents a freeway interchange project, the impact on **vulnerable systems users** may be considered marginal. Regardless, it is important to consider all users of the system and their corresponding safety requirements. For this case study, pedestrian activity should be discouraged on the major routes and thus, facilities to encourage pedestrian use should not be provided. The exception is the need to ensure that pedestrians are safe in the event of vehicle breakdown. Cyclists are currently restricted from the TCH facility, but effort should be made to safety accommodate them in the new planning solutions. This may reduce vehicle exposure, thereby improving overall safety. The safest option may include a separate facility (off the roadway), explicitly planned and designed for cyclists. If the cyclists are to be accommodated on a shared roadway, separating locations of concern and probable conflict will improve safety.

One effective way to minimize the consequence of an incident it is **reduce vehicle speeds**. Unfortunately, the objectives of many guiding principles, such an improved roadway geometry or reduced road friction may result in an increase in travel speed. There are two problems with high speed; the first, is simply the hazard associated with excessive speed for the roadway design, and the second is the hazard associated with a large speed differential between system users.

In formulating a planning option, it is important to determine locations where excessive speed could be a problem or locations of high-speed differential. For this case study, the following table (Table 5.5) summarizes the existing and planning criteria for the posted and design speed on the study corridors.

Table 5.5: Cape Horn Area Network Study: Design Speed

Roadway Section	Posted Speed (km / hr)		Design Speed (km / hr)	
	1998	2021	1998	2021
Trans Canada Highway				
Mainline	80 – 90	90	80 – 90	100
Ramps	50	80	50	80
Lougheed Highway	60 – 70	60 – 70	60 – 70	60 – 70
Mary Hill Bypass	70 – 80	70 – 80	70 – 80	70 – 80
United Boulevard	60	60	60	60

BC MOTH: Based on Cape Horn Area Network Planning Study – Planning Criteria.

A number of locations in the study area currently have speeding problems that contribute to collisions. This is particularly a problem for commercial vehicles traveling too fast and encountering difficult roadway geometry. In addition, given the potential increase in speeds for the 2021 target year, it is expected that the area may continue to suffer from a potential hazard as a result of excessive speed. A few examples of current and potential excessive speed and speed differential problems include:

- the TCH westbound traffic on the downgrade from the Port Mann Bridge having to encounter exit and entrance ramps,
- the TCH eastbound traffic exiting in the Cape Horn area to Lougheed Highway or other adjacent routes (truck roll-over problem area),
- the speed differential between on-ramp and mainline traffic connecting the TCH to the adjacent routes, or
- the potential for high speed differential between freeway traffic exiting the TCH connecting to lower standard roads (United Boulevard).

In these potentially problematic locations, efforts should be made to either provide generous geometric alignment or to increase roadway friction to control speed. In terms of process, it is important to recognize the locations where speed or speed differential may be a problem and to develop plans to address the problem or to reduce the traffic volume impacted by the speed problem.

The final element associated with the consequence component of the safety risk function is **roadside safety**. Ensuring a safe roadside environment will lessen the severity of off-road incidents should they occur. The potential for off-road incidents can be evaluated by identifying areas with poor horizontal alignment combined with the potential for excessive speed or in areas with high weaving volumes. Once potentially problematic locations are identified, efforts should be made to ensure that the adjacent roadside area is forgiving. For this case study, several locations were identified as potentially problematic, including:

- many of the connecting ramps between the different corridors where roadway geometry is constrained, or
- high speed weaving sections, connecting lower classification / lower speed roadways with the high-speed freeway (TCH).

Two options are normally available to address roadside safety concerns. The better of the two options is to ensure that the roadside environment is free and clear of all hazards and the roadside area is traversable and sufficiently wide to contain errant vehicles within the roadside area. The second option is to provide roadside barrier to protect the occupants of an errant vehicle from roadside hazards that cannot be removed. This option is less safe as the barrier poses a hazard in the roadside, although it is designed to reduce incident consequence.

5.8.2.4 Developing Safe Planning Options Summary

It became obvious in attempting to apply the guiding principles that it is difficult to quantify and explain each principle. Rather, it seemed more efficient to understand the intention of each guiding principle while formulating each option. Road planning and design is a creative process and any attempt to confine the process may result in the lack of consideration of suitable alternatives. The goals of the guiding principles are not to confine the creative process, but to ensure safety is properly addressed (Navin, 1992). As mentioned at the outset of this case study, it is intended that the guiding principles should be used as part of the process rather than applied independently (as undertaken for the case study).

5.8.3 Evaluating Planning Options (Post-Planning Stage)

The principle output from the planning phase, is the development of one or a few 'preferred' planning alternatives. These alternatives would be selected based on the success in meeting the goals and objectives set out at the beginning of the planning exercise. The objective at the post-planning stage is to evaluate the proposed options using a multiple-accounts evaluation process to select the 'best' planning option. Once the 'best' option is identified, there is a final opportunity to review the plan to determine if there are any safety concerns that may be addressed before the project moves into the design stages. This opportunity can be realized by undertaking a planning level road safety audit.

For this case study, it was possible to obtain two of the potential planning options for the Cape Horn Area Network study. These two options were subjected to a safety-based multiple accounts evaluation process and a planning level road safety audit to demonstrate the proactive road safety processes in the post-planning stage.

Two safety-related goals exist at this stage of the planning process:

1) to ensure that the guiding principles for road safety planning have been applied and are reflective in the details of the planning options, and
2) to ensure that no unexpected safety problem has surfaced in the formulation of the preferred plan.

Two planning options for the Cape Horn Study Area were obtained from the Ministry of Transportation and Highways, labeled 'Option 3' and 'Option 4'. Simple single line sketches were the output from the planning exercise, which provided the geometric configuration and the lane balance for the two schemes. The horizontal curve radius was the only detailed geometric element that was provided on the plans. The two options are shown in Figures 5.7 (a and b) and 5.8 (a and b). Figures labeled 'a', illustrate the western portion of the study area and figures labeled 'b' show the eastern portion of the study area.

5.8.3.1 Multiple Accounts Evaluation

The safety impacts of the two planning options were explicitly considered in the MAE process. Rather than using an aggregate safety measure such as the average collision rate to compare the two facilities, each option was reviewed in detail and several safety indicators were established. The safety considerations were also isolated from other MAE considerations, thus making safety more prominent in the MAE process. Unfortunately, the required collision prediction models do not exist for all categories of roads for this case study and therefore could not be used.

A total of five criteria were developed to assess the safety performance of the two planning options (Option 3 and Option 4). These criteria include:

1) The number of merging and diverging locations for each alternative was noted together with the number of weaving sections where the length that is available for a motorist to make the each weaving maneuver is considered short.
2) The number of conflict points of concern on each option was recorded to reflect the potential for collisions between the two schemes. The planning option with less conflict points would be considered the safer alternative.
3) The level in which the travel lanes are balanced was noted, focusing on the need for a motorist to change lanes due to unexpected lane dropping, recorded by the number of lane reductions on each plan.
4) The geometric alignment of the two options was also evaluated, based primarily on the radius of curves and the presence of difficult and unexpected compound curves, such as a compound curve that includes sequential curve radii of 125, 500, 250 meters respectively.
5) The impact of the two planning options on driver expectation was also evaluated based on complicated and/or confusing geometry. An example of this would include exit ramps far in advance of desired exit location, and potential problems with directional signing.

By reviewing the two 'preferred' alternatives, it became apparent that one option was considered 'superior' with respect to the expected safety operation. Option 4 surfaced as the 'better' option in comparison to Option 3, based on the criteria developed and summarized in Table 5.6 below. The frequency of merge, diverge and weaving sections were determined for both option 3 and option 4. It is clear that with the exception of merge points, that option 4 has less problematic locations. This is true for the number of conflict points, where option 4 has one less major conflict point that option 3. Lane balance, the horizontal alignment and the complexity of the proposed geometry also seem to favor option 4.

Table 5.6: Results of Safety MAE for the Cape Horn Area Network Study

No.	Safety Issue	Option 3	Option 4
1	Merge Locations	16	18
2	Diverge Locations	25	16
3	Weaving Sections	9	3
4	Conflict Points	9	8
5	Lane Balance	16	14
6	Horizontal Alignment	5	3
7	Complex Geometry	4	2

There are two conclusions that can be drawn from this safety MAE exercise. The first conclusion is that option 4 appears to be the 'better' of the two options based on the safety parameters examined. The second conclusion is that it would be very beneficial to complete a quantitative evaluation of the options in terms of the expected collision costs. This is due to the fact that there are many other considerations in the MAE process, and ultimately the decision to proceed with any option should be based on the economic benefits traded off against the economic costs. Again, once collision prediction models are fully developed, they may provide the opportunity to capture this requirement.

5.8.3.2 Road Safety Planning Audit

The MAE exercise identified Option 4 as the superior option and thus, will be used for the planning level audit. The results from the planning level audit on the 'best' option indicated that several safety concerns still existed even at this late stage in the planning process. It is not necessary to provide all the specific details of the planning level audit, but rather some examples of safety concerns are listed below. What is important to recognize, is that several safety concerns were identified, many of which could be addressed before the options move into the design stage.

Some typical examples of the safety concerns that arose during the planning level audit are listed below and shown in Figure 5.8:

1) There are many driver decision points at locations where the geometric alignment is difficult. Adequate warning or guidance signing may address some locations, but at other locations the alignment may be shifted to improve the decision opportunity.
2) There are some weaving locations that may be difficult and there may be an opportunity to separate these weaving maneuvers or increase the length available to make the required weaving movements.
3) The geometry associated with some of the conflict point locations and the network routing options may not adequately facilitate commercial vehicle movements.
4) There are some locations where the lane configuration and the lane balance is designed to support traffic demand, but for safety reasons, lane continuation may be preferable.
5) There is a possibility that the sight distance at many structures may be limited unless the horizontal and vertical alignments can be altered. The presence of traffic queues or incidents may compound this safety problem.
6) There are merge locations on curves and at structures that could be modified and re-located to improve safety performance.

These are generalized examples of a few safety concerns that were identified when Option 4 was audited. Depending on the magnitude of the concerns, the issues can be addressed by the planners and as a result, the preferred option can be modified. Alternatively, the safety concerns can be addressed at the design stages.

There is some debate on whether or not the safety auditors should make improvement recommendations to address safety concerns that were identified (Jordan, 1993). Some believe that audit process should only identify problems / concerns and then it is up to the planners or designers to improve the audited alternative. Others believe that there is some value in having the safety auditors make recommendations on improvement options.

5.8.4 Summary

This real-world case study has been presented to demonstrate the framework for proactive road safety planning. Unfortunately due to the urban nature of the study location, the limited scope of the project and the relatively small study area, the demonstration of the proactive planning framework was somewhat limited. Regardless, the case study was useful in presenting the processes to support the recommended framework.

The application of the guiding principles to reduce road safety risk was useful to determine and test the proposed framework in influencing planning decisions. At the post-planning stage, two options were suggested by the Ministry and were used to conduct a multiple-accounts evaluation process (MAE). One option surfaced as superior with respect to the expected safety performance (Option 4) and this option was then subjected to a planning level audit. Even at this final stage of the planning process, several safety issues were identified that, if acted upon, could result in an overall improvement to the safety performance of the study area.

5.9 Summary and Conclusions

In developing a systematic framework for proactive road safety planning, it was first important to recognize the opportunities to provide input in the process. Two opportunities exist to provide safety input in the planning process:

1) to provide safety guidance to influence and develop planning options, and
2) to evaluate the planning options that are generated by the planning team.

The methodology to support the framework for proactive road safety planning is based on the concept of road user risk. A road safety risk function was presented in an earlier chapter and is based on three components; namely exposure, probability and consequence. Each component of the road safety risk function has several specific factors used to explicitly consider safety impacts, as shown in Table 5.7. Associated with each factor are several guiding principles used to evaluate safety impact of planning decisions (the details are included in the body of the report).

Table 5.7: Factors Used to Influence Road Planning

Exposure		
1.	Land Use	- Assign land use to reduce time, distance or need to travel.
2.	Network Shape	- Develop network shape to reduce amount of traffic and travel distance.
3.	Mode Choice	- Facilitate and encourage alternate modes of transportation.
Probability		
1.	Maneuverability	- Attempt to maximize the degree of maneuverability on the system.
2.	Geometric Design	- Provide for generous and appropriate geometric design features.
3.	Functionality	- Ensure roadway function is homogeneous, appropriate and predictable.
4.	Conflicts	- Attempt to minimize the amount of conflicting traffic on the system.
5.	Road Friction	- Avoid the creation of road friction where it could cause safety problems.
6.	Road Predictability	- Guide planning to ensure the road conveys a clear message to drivers.
Consequence		
1.	Vulnerable Users	- Consider and facilitate the needs of vulnerable system users.
2.	Reduce Speed	- Reduce vehicle speed in areas of high risk.
3.	Roadside	- Ensure the roadside provides a safe environment for errant vehicles.

The second opportunity to be proactive in the road planning process is to provide an assessment of the options that are developed through the planning process. Two procedures are suggested; one to determine the preferred plan from a series of potential options and the second, to "fine-tune" the preferred option and to have an final opportunity to review the plan before it enters the design stages.

The first procedure is a multiple-accounts evaluation (MAE) procedure used to determine the optimal plan from a series of potential options. Collision prediction models can be used (if available) to provide a reliable estimate to quantify and compare the benefits of each option. If prediction models are not available, then a qualitative assessment can be used to determine the relative benefits of each option. The final opportunity to influence the plan for a new roadway is to conduct a road safety audit. Procedures are available and were described to undertake a road safety audit at the planning stage.

In order to test the framework and process for road safety planning, a case study was conducted using an actual highway-planning project located in the Lower Mainland of British Columbia. The objective was to test the suitability and validity of the recommended framework and procedures. For the case study, the starting point was a 'blank-sheet' and an improvement option was considered based solely on the application of the guiding principles for road safety planning. Many of the guiding principles associated with exposure, probability and consequence were applied to the Cape Horn Area Network Study and the results indicated that the proposed framework was effective in isolating and explicitly considering safety concerns.

Perhaps the most effective tool to quantitatively assess safety impact was with the use of collision prediction models and several examples were used to demonstrate these tools. Other guiding principles were more qualitatively assessed but were considered useful in identifying potential problems, as well as opportunities to enhance safety.

In some cases, it became obvious that it was difficult to quantify and explain each guiding principle. Rather, it seemed more efficient to understand the intention of each guiding principle while formulating each planning option. When this is the case, it is recommended that the guiding principles should be used as a safety 'checklist' to assist engineers and planners in the accommodation of safety issues. It is important to stress that it is the intention that these guiding principles should be used as part of the process rather than applied independently.

The case study was undertaken to demonstrate the framework for proactive road safety planning. Some limitations did exist with the case study, but it did reflect a real-world problem and it was useful in presenting the processes to support the recommended framework. During the planning stage, the application of the guiding principles can influence planning decisions and explicitly address safety. At the post-planning stage, the two proactive planning techniques (the MAE process and road safety auditing) were completed, which identified safety issues that if acted upon, could result in an improvement safety performance.

6.0 COLLISION PREDICTION MODELS FOR SAFETY MANAGEMENT

Collision prediction models (CPMs), or often referred to as accident prediction models have been available and described in road safety engineering literature for many years. However, the usefulness and application of these models for use in road safety management has been very limited. The preceding chapter lists CPMs as an opportunity to proactively manage road safety and thus, this chapter describes how CPMs are developed and how CPMs can be used more effectively for proactive road safety management. The CPM developed for this research pertains to a provincial rural highway.

There are several reasons for the limited usefulness and application of CPMs. First, to be effective, the CPM should be relevant and reflect local conditions. Thus, a CPM developed in another jurisdiction and under different conditions (different road classifications, different traffic characteristics, different collision reporting practices, etc.) may not yield accurate results locally. Secondly, a CPM should be current to reflect safety advancements such as the increased use of airbags or improved road design standards. CPMs developed some time ago may also suffer from a weakness in the developmental methodology, whereas models developed more recently will reflect current knowledge and techniques for modeling. Finally, there has been a problem with practitioner's ability to make use of the CPMs to improve the management of road safety.

This chapter is divided into six sections. Section 6.1 provides background information and a review of the literature associated with CPMs for rural roadways. Section 6.2 describes the data that is used to develop the CPM and Section 6.3 describes the results of the modeling, presenting the developed CPM and indicators of success for the model. Section 6.4 provides a simple demonstration of the application of the CPM for proactive road safety planning. Finally, Section 6.5 will summarize the chapter, stating the conclusions made from the research.

6.1 Background and Literature Review

A roadway network is often separated into two broad categories for safety evaluation due to significant differences in operation. These two categories include intersections and sections (i.e., between intersections). Collision prediction models are usually developed for these two categories of roadway elements, and within each of these categories, the roadway can be further categorized based on specific features of the intersection or section. For example, an CPM developed for an intersection can be categorized by road class (urban, sub-urban, or rural), by intersection type (4-way, t-type intersection or roundabout), by type of control (signalized, non-signalized) and so on.

Some local CPMs have been developed, including models for urban signalized and non-signalized intersections (Rodriguez and Sayed, 1999) and for urban arterial roadways (Sawalha and Sayed, 2001). The focus for this research will be on rural two-lane conventional highways where no local CPMs currently exist and because this highway type represents approximately 80 percent of the total primary highway network in BC (primary highways). Significant research work has been done outside of British Columbia to develop CPMs for rural roadways that will be summarized below. The literature review is limited to the most relevant literature published within the last ten years.

Vogt and Bared (Vogt, 1998) used data from Minnesota and Washington to develop CPMs for rural two-lane highways. The quantity, quality, and variety of the data make this study of special interest, which included data on traffic, horizontal and vertical alignments, lane and shoulder widths, roadside hazard rating, lane channelization, and the number of driveways. Negative binomial regression was used for modeling and the models included the state (Minnesota or Washington) as one of the predictive variables. The collision frequency is dependent on most of the roadway variables collected and the study recommends the development of adjustment factors for different regions. One example of the model is given in equation 6.1.

$$
\begin{aligned}
y_{freq} = \quad & EXPO \times e^{(0.17+0.14State-0.28LW-0.19SW+0.067RHR=0.014DD} \\
& \times\left[\sum_i WH\{i\} \times e^{0.014DEG_m\{i\}}\right] \\
& \times\left[\sum_i WV\{j\} \times e^{0.13V_m\{j\}}\right] \\
& \times\left[\sum_i WG\{k\} \times e^{0.11GR\ \{k\}}\right]
\end{aligned}
\qquad (6.1)
$$

where y_{freq} = mean number of collisions expected in 5 years.

EXPO = exposure in million vehicle kilometers

State = location (Minnesota = 0, Washington = 1)

LW = lane width in meters

SW = shoulder width in meters

RHR = roadside hazard rating

DD = driveway density (per kilometer)

DEG{i} = degree of curve for horizontal curve number {i} in a segment

V_m{j} = vertical curve grade rate for curve number {j} in a segment

GR{k} = absolute grade for straightaway number {k} in a segment

WH{i} = weight for horizontal curve {i} (curve length / segment length)

WV{j} = weight for vertical curve {i} (curve length / segment length)

WG{k} = weight for grade number {k} (grade length / segment length)

A study by Tarso et al., (Tarso, 1997) focused on developing relationships between collision rates and the operational capacity of rural interstate highways in Illinois. CPMs were developed using the volume to capacity ratio (V/C) as one of the predictive variables. A concept of modified capacity is introduced, where the design capacity is adjusted to incorporate other geometric factors. This modified capacity includes variables that may have a significant impact on collision occurrence, but are not directly included when capacity is calculated. A model is developed for rural interstate highways and is based on data compiled over six years. This model is part of a more comprehensive study where several other predictive models were created for urban interstate highways, urban two-lane highways, and urban and rural multilane highways. The recommended two lane rural model was proven to be valid and is shown in equation 6.2.

$$Acc/mi = 0.803 + 8.502 \times (V/C) - 0.003 \times MW - 0.004 \times SR \tag{6.2}$$

where Acc/mi = collisions per lane per mile, averaged over six years

V/C = volume to capacity ratio

MW = median width in feet

SR = Surface rating index

A study by Kalokota (Kalokota, 1994), aimed to model the influence of the geometric design variables on traffic collisions on two-lane rural highways in Utah. The objectives of the study were to review previously developed relationships between collisions and geometric design elements, to identify significant model variables in developing the CPMs, and to examine the transferability between models. The study revealed that the exposure in terms of distance traveled (section length) is the most significant variable in the models developed, with other variables being less important in the overall prediction. The best CPM for two-lane rural roads in northern Utah is given in equation 6.3.

$$AR = 0.0092 + 0.016(D) + 3.5(L) - 0.02(L)(SWR) - 0.006(L)(D)(G)(SWR) \tag{6.3}$$

where AR = collision rate per thousand vehicles per year

D = degree of curve

L = section length in miles

G = percent grade

SWR = right shoulder width in feet

Persaud (Persaud, 1991) developed a negative binomial regression model for rural freeways in Ontario, as shown in equation 6.4. Geometric design variables were not used in the development of these models since it was believed that freeway sections tended to have similar characteristics, with high design standards. In developing the models, the segment length was forced constant at one-kilometer in length, thus providing an estimate in collisions per year per kilometer.

$$Acc / yr / km = 0.6278 \times \left(\frac{AADT}{1000} \right)^{1.024} \tag{6.4}$$

where Acc/y/k= freeway collisions per kilometer per year

L = segment length in kilometers

AADT = average annual daily traffic

Persaud (Persaud, 1994) also describes the development of CPMs used to estimate the collision potential on rural road sections in Ontario. Regression models were developed using Ontario data for traffic and geometric characteristics. The models were developed using data from 1988 and 1989 and the models were validated using data from 1987.

Josha and Garber (Josha, 1990) developed Poisson regression models that related commercial vehicle collision occurrence with various traffic and geometric road characteristics on rural highways in Virginia. Sites were selected and grouped into three environments based on roadway configuration and traffic volumes, and a CPM was developed for each category. Section length was restricted to a maximum of 2 miles in length and surrogates were used to reflect the horizontal and vertical alignments in model development. The following Poison regression model was developed for rural four-lane, divided roadways with an AADT of less that 15,000.

$$Acc / yr = 9 \times 10^{-8} \times (SCR)^{0.0471} \times (AADT)^{1.4358} \times (TPER)^{1.5232} \times (SL)^{0.3826} \tag{6.5}$$

where Acc/y/k= collisions per year

SCR = slope change rate (surrogate for vertical alignment)

AADT = average annual daily traffic

TPER = percentage of trucks in the traffic stream

SL = segment length in kilometers

The Transportation Association of Canada published a report (TAC, 1996) which reviewed the use of collision prediction models and investigated the usefulness of the models for the safety component of MicroBENCOST analysis software. The report recommends the use of several CPMs for different roadway features including rural highways. The recommended rural highway model is based on work by Persaud (Persaud, 1991), given in equation 6.6 for rural highways with lane widths greater than 6.1 meters and a shoulder width less than 1.8 meters.

$$Acc/yr/km = 0.0025 \times \left(\frac{AADT}{1000}\right)^{0.733} \tag{6.6}$$

where: Acc/yr. = total collisions per kilometer per year
AADT = average annual daily traffic

The Ministry of Transportation of Ontario completed another recent Canadian effort in the area of CPMs. In a report titled the Science of Highway Safety, (MTO, 1998), a complete suite of collision prediction models were developed for the provincial highways in Ontario. The CPMs were developed using Ontario traffic data that reflected the different categories of provincial roads but did not include roadway geometric features as predictive variables. For each category of road, three models were developed to reflect the three common severity levels including a model for fatal collisions, injury collisions and property damage only collisions. An example of the CPMs developed for a rural, Kings Arterial highway with less than four lanes are shown in equation 6.7.

$$\begin{aligned} Fatal\ Acc/yr &= 0.0000099 \times L \times (AADT)^{0.94653} \\ Injury\ Acc/yr &= 0.0001664 \times L \times (AADT)^{0.94653} \\ PDO\ Acc/yr &= 0.0003589 \times L \times (AADT)^{0.94653} \end{aligned} \tag{6.7}$$

where: Acc/yr. = total collisions per kilometer per year (fatal, injury or PDO)
AADT = average annual daily traffic
L = segment length in kilometers

CPMs are also described and promoted in the recently released Geometric Design Guide for Canadian Roads, published by the Transportation Association of Canada (TAC, 1999). In this national road design manual, CPMs are referred to as "safety performance functions" (SPFs) and are included wherever possible for different road design features, based on the best available knowledge. The intent of using SPFs is to get designers to have a better understanding of the safety impact of design decisions. One example of a SPF is shown in equation 6.8 for the safety effects of horizontal curves (based on Hauer, 1998).

$$A/MEV = \left((0.96 \times L) + \left(\frac{0.0245}{R} \right) - (0.012 \times S) \right) \times 0.978^{(3.3W-30)} \tag{6.8}$$

where: A/MEV = collisions per million vehicles entering a curve (both directions)

L = segment length in kilometers

R = curve radius in kilometers

S = to consider spiral curves (S=1 with spiral, S=0 for no spiral)

W = roadway width (lanes plus shoulders) in meters

As can be deduced from the literature review, considerable research has been undertaken in the area of collision prediction models. The models have been developed for many objectives and jurisdictions. However, the use of the models by practitioners is rare and as a result, the value of the research is reduced. The development and application of a CPM is provided in this chapter to demonstrate how CPMs can be used by practitioners for road safety management.

6.2 Collision and Roadway Data

The data used to develop the collision prediction model came from a variety of sources within the BC Ministry of Transportation and Highways. Four sources of data were obtained and compiled, including the collision data, traffic volume data, road classification data and road character data. The data was associated with rural highways located in the Okanagan and Kootenay regions of the province.

The collision data was obtained from a database called the Highway Accident System (HAS) maintained by the Highway Safety Section of MoTH (as described earlier). Considerable limitations with the collision data were described in previous chapters but for this project, effort was made to ensure that the collision data used did not suffer from a these problems (i.e., the data was of high quality and did not suffer a deterioration over time).

Traffic volume data was obtained from the Traffic Information Management System (TIMS) maintained by MoTH. This system contains the traffic volumes recorded from permanent and temporary count stations located on provincial highways. TIMS data includes the average annual daily traffic (AADT) and the summer average daily traffic (SADT). The AADT was used to develop the CPMs.

MoTH has several different road classification schemes according to different objectives from the road authority. For example, there is a 'safety' classification used by the Safety Branch, a 'road function' classification used by the Planning Branch and a 'pavement quality' classification used by the Geotechnical Branch. The road function classification was used for this research, which categorizes roads by land use (urban or rural) and function (freeway, expressway, or conventional). Rural conventional roads were used to develop the CPMs.

The last data source used in developing the CPMs was the road character data. This data was obtained from planning documents compiled in support of several major planning projects within the Thompson - Okanagan area of the province. The road character data was compiled from 'as-built' drawings and the photo-log system (a system that measures and records road information using on-board electronic devices). The data included a measure of the horizontal curve, road grade, the vertical curve, shoulder width, lane width, access density and other data elements. The road character data was presented in a series of 'strip maps' and included an aerial photograph, useful in dividing corridors into homogeneous segments, a requirement of the modeling exercise.

A summary of the data elements that were collected in advance of the development of the CPMs is provided in Table 6.1. Included in the table is a description of each CPM variable, the variable name, minimum value, maximum value, and the total and/or average are provided (if meaningful). Note that not all variables are used in the development of the CPM.

Table 6.1: Summary Statistics for Rural Conventional Highway CPM

Data Description for CPM Variables	Variable Name	Minimum Value	Maximum Value	Total and/or (Average)
Total number of road segments used to develop CPM:	N	n/a	n/a	155 n/a
Segment length: (kilometers)	L	0.50	5.88	330.80 (2.13)
Average annual daily traffic: (vehicles per day)	AADT	3490	9500	n/a (5549)
Total number of collisions: (collisions per 3 years)	ACC	0	69	1589 (10.3)
Total number of severe collisions: (severe collisions per 3 years)	SEVACC	0	31	596 (3.8)
Degree of horizontal curve [1]: (degrees per 100 meters)	Hm	0.0	24.3	n/a (5.17)
Crest curve grade rate [2]: (percent per 100 meters)	VmC	0.00	6.06	n/a (0.86)
Shoulder width: (meters)	SW	0.75	4.50	n/a (2.21)
Posted speed: (kilometers per hour)	PS	80	100	n/a (91.1)
Absolute grade: (percent)	GR	0.00	5.49	n/a (1.95)

1. Hm = the sum of the weight for horizontal curve (i) multiplied by the degree of curve for horizontal curve (i) in degrees per 100 meters. The weight per horizontal curve is defined as the length of horizontal curve (i) divided by the total length of the segment (L).
2. VmC = the sum of the weight for vertical crest curve (j) multiplied by the crest curve grade rate for crest curve (j) in percent per 100 meters. The weight for vertical crest curve is defined as the length of vertical curve (j) divided by the total length of the segment (L).

There are several considerations associated with the development of a collision prediction model for rural highways. These modeling issues are discussed in detail in Sawalha and Sayed (Sawalha and Sayed, 2001), and include the following issues, which were considered in the development of the CPM described herein.

1) that the mathematical form of the collision prediction model produces results that are logical,
2) that exposure variables (volume / length) be included as explanatory variables and collision frequency should be the response variable, and
3) that the segments used for modeling are produced based on homogeneity in roadway character (design and traffic features).

6.3 Results of GLIM Modeling for Rural Highways

As described by Sawalha and Sayed (2001), the staring point for developing a collision prediction model is a basic model containing the exposure variables (volume and length), considered fundamental to any model. The approach used to develop the basic CPM for rural highways was described in detail Chapter 3 of this thesis (Claims Data for Safety Evaluation). The generalized linear regression modeling approach (GLIM) is used and the model structure, model development and tests of significance for the model are described on pages 38 to 40. The developed model was produced using a negative binomial error structure because of the over-dispersion in the data (as described previously).

A basic model was developed that predicts the three-year collision frequency based on the segment length, measured in kilometers (L), and the main-line traffic volume given by the average annual daily traffic volume (AADT). The formulation of the model, the model parameters and the indicators for the model significance, including the t-ratio, the κ value, the *Pearson* χ^2 and the scaled deviance are presented in Table 6.2. Note that a description of the indicators for model significance was also provided in Chapter 3.

Table 6.2: Collision Prediction Model for Rural Highway

Model Formulation	t-ratio		κ	Pearson χ^2 (χ^2 test)	S.D. (DoF)
$Collisions/3yrs = 0.001302 \times (L \, x \, AADT)^{0.9645}$	A_o A_1	5.1 3.4	1.34	171 (186)	179 (156)

Once the basic model is developed, then other variables (traffic or design variables) can be added and the quality of the new model is evaluated with the inclusion of the new variable. Sawalha and Sayed (2001) indicate that the selection of the independent variables (other than the exposure variables) to be included in the collision prediction models depends on the intended purpose and application of the model. If the model is to be used for evaluating safety potential, identifying or ranking collision prone locations or before and after analysis, then additional variables are only added if the predictive capability of the model is maintained. In this case, the decision on whether to include a variable in the model is based on two criteria:

1) whether the t-ratio of the variable coefficient is significant at the 95 percent confidence level, and
2) whether the addition of the variable to the model causes a significant drop in the scaled deviance (SD) at the 95 percent confidence level.

Alternatively, if the model is to be used for safety planning or evaluating the effect of a variable on collision frequency, then retaining a variable in the model is based only on the first criterion.

The variables investigated for inclusion in the CPM were listed in Table 6.1. The variables that were successful included the design variables of shoulder width, horizontal curve, and vertical crest curve (as well as the exposure variables of volume and segment length). The developed CPM is shown in equation 6.9, and the parameter estimates of the model, including the t-ratio, the scaled deviance, the κ value, and the Pearson χ^2, are shown in Table 6.3.

$$Col./3yrs = 0.000433 \times (L \times AADT)^{1.1} \times e^{(-0.2032SW)+(0.0476Hm)+(0.09189VmC))} \quad (6.9)$$

where:

Col./3yrs	= expected collision frequency in three years,
L	= length of the segment in kilometers,
AADT	= traffic volume in vehicles per day,
SW	= shoulder width in meters,
Hm	= degree of horizontal curve (degree/100m.),
VmC	= degree of vertical crest curve (degree/100m.)

Table 6.3: Summary Statistics for CPM for Rural Conventional Highways in BC

Model Variable	Name	Coefficient Value	T-ratio	SD (DoF)	κ	Pearson χ^2 (χ^2)
Base coefficient	a_0	0.000433	5.96	169.03 (150)	1.74	125.1 (178.5)
Exposure (L*AADT)	a_1	1.1	7.84			
Shoulder Width	b_1	-0.2032	2.12			
Horizontal Curve	b_2	0.0476	3.29			
Vertical Curve	b_3	0.09189	1.97			

From the information in Table 6.2, it is noticed that the t-ratios of each parameter estimate are all significant (greater than 1.96). The Pearson χ^2 value indicates significance at the 5% level.

Figure 6.1 shows how the function for the variance of the observed collisions, as obtained from the CPM, fits the average squared residuals. The continuos curve is the variance function line and each dot is the average of the predicted collision frequencies and the average of the residuals for a sequenced group of segments (i.e., the first ten segments sorted by the predicted collision frequency). The figure shows a reasonably good fit. Figure 6.2 show that the Pearson residuals are clustered around zero, indicating a reasonably well fitted model.

6.4 Application of the CPM for Proactive Road Safety Management

A simple example is provided to demonstrate the usefulness of the developed CPM for proactive road safety management. Consider a road planning project where two options are developed to connect locations 'A' and 'B'. Option 'A' is a low cost option requiring marginal earth works and as such, suffers from poor horizontal and vertical alignments, as well as confined cross-sectional design elements. Alternatively, Option 'B' is a high cost alternative that involves considerable earth works in order to achieve high design standards (wide shoulders and generous horizontal and vertical alignment). The data elements necessary to use the CPM are listed in Table 6.4.

Table 6.4: Illustrative Example of CPM for Proactive Planning

Traffic / Design Parameter	Option 'A'	Option 'B'
AADT	6200 vpd	6200 vpd
Segment Length	2.7 km.	2.3 km.
Shoulder Width	1.5 m.	2.5 m.
Hm	10.4	5.2
VmC	1.7	0.9

Using the CPM in equation 6.9, the expected collision frequency can be calculated for the two options as follows:

Option 'A': $Coll./3yrs = 0.000433 \times (2.7 \times 6200)^{1.1} \times e^{(-0.2032 \times 1.5)+(0.0476 \times 10.4)+(0.09189 \times 1.7))} = 23.7 coll./3yrs.$

Option 'B': $Coll./3yrs = 0.000433 \times (2.3 \times 6200)^{1.1} \times e^{(-0.2032 \times 2.5)+(0.0476 \times 5.2)+(0.09189 \times 0.9))} = 13.5 coll./3yrs.$

By applying the CPM for the two options proposed, it is determined that one option is superior in terms of the expected safety performance. This is an intuitive result given the design characteristics of the options. A cost per collision can then be applied to the two options and the life cycle costs can be calculated and considered with other road authority objectives to determine the optimal alternative. This demonstrates how CPMs can be used in support of proactive road safety planning decisions.

6.5 Summary and Conclusions

The main objective for this chapter was to develop a collision prediction model to reflect local conditions for the purposes of application in proactive road safety management. The research investigated several geometric variables that were believed to influence the frequency of collision occurrence. A valid collision prediction model was developed for rural conventional highways (i.e., 2-lane highways) using the independent variables of segment length, volume (AADT), shoulder width, and measures of horizontal curve and vertical crest curve.

Several reasons were cited at the beginning of this chapter concerning the limited application of CPMs among practitioners. First, was that CPMs should be developed to reflect local conditions as models developed in other jurisdictions may not yield accurate results locally. This was achieved by the development of a CPM specific for BC conditions. The second reason was that the models should be current to reflect general safety advancements (safer vehicle design) and state of the art modeling techniques. These were accommodated in the development of the CPM since it utilized current data and the GLIM modeling technique was used (considered superior to conventional techniques as described in Chapter 3 of this thesis). The demonstration of an application of the CPM addresses the third reason for the limited use of CPMs; the lack of understanding on how to make use of CPMs for road safety management.

7.0 CONCLUSIONS AND CONTRIBUTIONS

Several obstacles that are associated with the management of road safety were presented in the Introduction chapter of this thesis. These obstacles define the problem statement for this research endeavor, which is stated as follows:

> *To explore new opportunities to develop and improve the evaluation techniques and processes that can be used in support of the effective management of road safety infrastructure.*

This chapter provides a summary of the conclusions and contributions that are derived from this research work. The work offers four separate initiatives that attempt to address the problem statement. These initiatives are summarized as follows:

1) To explore the use of auto insurance claims data for road safety analysis in an attempt to address the problem of a dependency on the deteriorating collision data.
2) To develop a subjectively based, observation technique that can be used for road safety analysis, based on a concept of road-user risk, again to address the problem of a dependency on collision data.
3) To provide a framework and process to support proactive road safety planning and design, describing how the framework and processes should be applied.
4) To introduce improved techniques to evaluate safety performance by developing collision prediction models that can address problems with proactive road safety management.

The conclusions associated with each initiative is summarized below, followed by the contributions that are made in support of advancing the knowledge with the management of road safety.

7.1 Summary and Conclusions from Research

7.1.1 Claims Data for Road Safety Evaluation

Chapter 3 presented some preliminary results on the use of auto insurance claims data for the monitoring and evaluation of road safety. The main research objective was to investigate a new approach to evaluate road safety by developing and applying a Claim Prediction Model (CLPM). The CLPM was developed using auto insurance claim data available through the Insurance Corporation of British Columbia (ICBC). The motivation for this research was to address problems associated with collision data and to determine if the claims data could be used in place of collision data.

The data was obtained from ICBC and from local road authorities, and included data for 108 urban, signalized intersections located in the lower mainland area of British Columbia. The data included auto insurance claims data, collision data (total and injury collisions), and the traffic volume data. This data was used to develop three prediction models; one to predict the number of claims, the second model to predict the total number of collisions and the third model that predicts the number of injury collisions. All three models predict the collision frequency based on the major and minor traffic volumes entering the intersection. The generalized liner modeling approach (GLIM) was used to develop the prediction models, as it was shown to overcome shortcomings associated with conventional linear regression.

The significance of the prediction models was evaluated in many ways. These measures include the scaled deviance (SD), the χ^2 value, the *Pearson* χ^2 statistic, and the t-ratio test. All three models were shown to have a relatively good fit and the value calculated for the t-ratios for all independent variables were significant. Three graphical techniques were also presented to demonstrate the goodness of fit of the models. Overall, each of the three prediction models is considered to be valid and fit the observed data very well.

The model predicts the expected three-year frequency of claims based on the major and minor road traffic volumes, input in vehicles per day (1000s) as shown below in equation 7.1

$$Claims\,/\,3yrs = 2.7429 \times \left(\frac{AADT_{maj\ \mathrm{rd}}}{1000}\right)^{0.8256} \times \left(\frac{AADT_{\mathrm{mnr\ rd}}}{1000}\right)^{0.4028} \tag{7.1}$$

Two applications for the CLPM were provided to demonstrate the usefulness in road safety engineering and analysis. The first application was the identification of problem locations and the second application was the ranking of these problem locations. For the first application, the Empirical Bayes refinement approach (EB) was used to improve the reliability of location specific predictions thereby improving the application of the claim prediction model. A four-step process was used to identify problem sites and included a numerical example. The process identified 40 locations from the list of 108 intersections as being prone to auto-insurance claims.

The second application of the CLPM was the ranking of problem locations and for this application, two ranking criteria were suggested to satisfy different priority objectives. The first objective attempts to identify locations where there is a large difference between the EB estimate and the predicted (normal) frequency. The second objective attempts to ensure that the risk at all locations is similar, by calculating the ratio of the EB estimate to the predicted (normal) value. The two ranking criteria generated by the claims data was then compared to the results produced by the collision information (both total collisions and injury collisions).

The level of agreement between the rankings was considered very good for the relationship between claims versus total collisions. Thus, it was concluded that the claims data was useful for road safety management.

7.1.2 Development of a Road Safety Risk Index

Chapter 4 describes the development of a subjectively based, observation technique based on a concept of road-user risk that can be used for road safety analysis. Six objectives were specified for success in developing a Road Safety Risk Index (RSRI), including that the process was quantifiable, replicable, flexible, cost-efficient, a valid, and that the RSRI results supported road safety analysis.

The reliability of the RSRI process stems from well-defined and quantifiable characteristics of road features that are studied and scored while completing a drive through review. These scores are combined to produce an overall road safety risk, formulated by combining the three components of risk; namely, the exposure of road users to road risks, the probability of becoming involved in a collision, and the resulting consequences should a collision occur. Quantification facilitates the safety analysis to identify and rank problematic segments.

By providing definitive guidelines on how to assess the three components of road safety risk, the process can be made replicable with consistent results produced independent of the observer. The statistic kappa was used in the case study to determine the consistency and the reliability of the risk assignment between observers. The level of agreement was acceptable, thereby supporting the requirement for a replicable RSRI process.

A systematic process was described to determine which road features should be investigated, as well as how each feature should be evaluated during the drive through review. It was not reasonable, nor necessary to list all possible road features associated with the many different road types. Rather, several typical road features associated with rural and urban roads were provided to illustrate the process. This accommodated another objective: that the RSRI process is flexible and can adapt to the needs of many users and differing conditions.

At times, the collection of data can be a cost-prohibitive undertaking, and thus developing a costly data collection process to obtain the road safety risk index would not be considered successful. The process developed for the RSRI is considered to be cost-effective and can be completed before significant and costly decisions are made regarding road safety improvements. The RSRI can also assist in formulating improvement plans, and by completing a drive through review, the need for a visit may be reduced or in some cases, eliminated.

The validity of the RSRI was evaluated by comparing the results of the risk index with an objective safety measure defined as the 'potential for improvement' (PFI), defined as the difference in the existing and expected collision frequencies. Accurate estimates of the existing and expected collision frequencies were obtained by using a collision prediction model and applying the Empirical Bayes technique. The Spearman's rank correlation coefficient was then used to determine the agreement level between the RSRI and the PFI. Homogeneous segments were ranked according to both the RSRI and the PFI, with the results of the Spearman correlation indicating agreement at a 99% significance level.

The corridor used for the case study (the Trans Canada Highway: Kamloops to Alberta) was selected in part, because it was the focus of major planning project. With the cooperation from staff from the BC Ministry of Transportation and Highways, the RSRI was critiqued for its usefulness in road safety analysis. The results from the RSRI were used in combination with the collision analysis and a stakeholder consultation process in formulating a safety master plan for the case-study corridor. This safety master plan represented one component of the overall upgrading plan for the Trans Canada Highway Corridor. In fact, since the critique and testing of the RSRI and due to the ongoing deterioration of collision data for provincial highways, the BC Ministry of Transportation and Highways has requested that a drive through safety review (based on the RSRI process) be completed when highway corridor plans are formulated.

7.1.3 Framework for Proactive Road Safety Planning

Chapter 5 addresses an evolving need of how to deal with road safety in a proactive manner. The chapter describes the development of a systematic framework for proactive road safety planning. A proactive approach to deliver road safety is intended to complement the more traditional, reactive methods currently in use. However, there is currently a poor understanding of how to proactively address road safety.

Three specific obstacles associated with a proactive approach safety planning were described in detail, and include the following:

1) a lack of opportunity within the traditional transportation planning process to explicitly consider road safety issues,
2) a lack of the necessary methodology and reliable tools to evaluate road safety in a proactive manner, and
3) a lack of a systematic process and framework to explicitly consider road safety issues.

The first objective for this component of the research was to identify the opportunities that are available to provide the safety inputs into the planning process. Two opportunities were identified. The first opportunity to provide explicit safety influence is by influencing the planning decisions used in developing the potential solution options. The value of this opportunity is that safety is "built-in" as each planning option is formulated. A second opportunity to influence the road safety performance within the planning stages is to evaluate the planning options that are generated by the planning team. This opportunity is characterized by optimization and auditing functions, which ensure that the overall safety performance is maximized. This provides a valuable input to the process and can result in the modification of proposed planning options before entering the design stages.

The second objective for part of the research was to develop the methodology to support a framework for proactive road safety planning. The framework is based on the concept of road user risk, as defined in Chapter 4 (based on exposure, probability and consequence). Each component of the risk function has several factors used to explicitly consider safety impacts, as summarized in Table 7.1. Associated with each factor are several guiding principles that are used to evaluate and influence the safety impact of planning decisions (first opportunity). Advice on how to quantify each of these guiding principles is provided.

Table 7.1: Factors Used to Influence Road Planning

Exposure		
1.	Land Use	- Assign land use to reduce time, distance or need to travel.
2.	Network Shape	- Develop network shape to reduce amount of traffic and travel distance.
3.	Mode Choice	- Facilitate and encourage alternate modes of transportation.
Probability		
1.	Maneuverability	- Attempt to maximize the degree of maneuverability on the system.
2.	Geometric Design	- Provide for generous and appropriate geometric design features.
3.	Functionality	- Ensure roadway function is homogeneous, appropriate and predictable.
4.	Conflicts	- Attempt to minimize the amount of conflicting traffic on the system.
5.	Road Friction	- Avoid the creation of road friction where it could cause safety problems.
6.	Road Predictability	- Guide planning to ensure the road conveys a clear message to drivers.
Consequence		
1.	Vulnerable Users	- Consider and facilitate the needs of vulnerable system users.
2.	Reduce Speed	- Reduce vehicle speed in areas of high risk.
3.	Roadside	- Ensure the roadside provides a safe environment for errant vehicles.

Two procedures are suggested to ensure that safety performance is maintained in the post-planning stage (second opportunity). The first procedure is a multiple criteria procedure used to determine the optimal plan with respect to safety. The second procedure to influence the plan for a new roadway is to conduct a road safety audit. Procedures are available and were described to undertake a road safety audit at the planning stage.

The final objective was to address the lack of a systematic process and the necessary framework to explicitly consider road safety issues within the road planning process. The opportunities to provide safety input into the planning process and the methodology was combined to form a framework for proactive road safety planning, which is presented graphically in Figure 7.1.

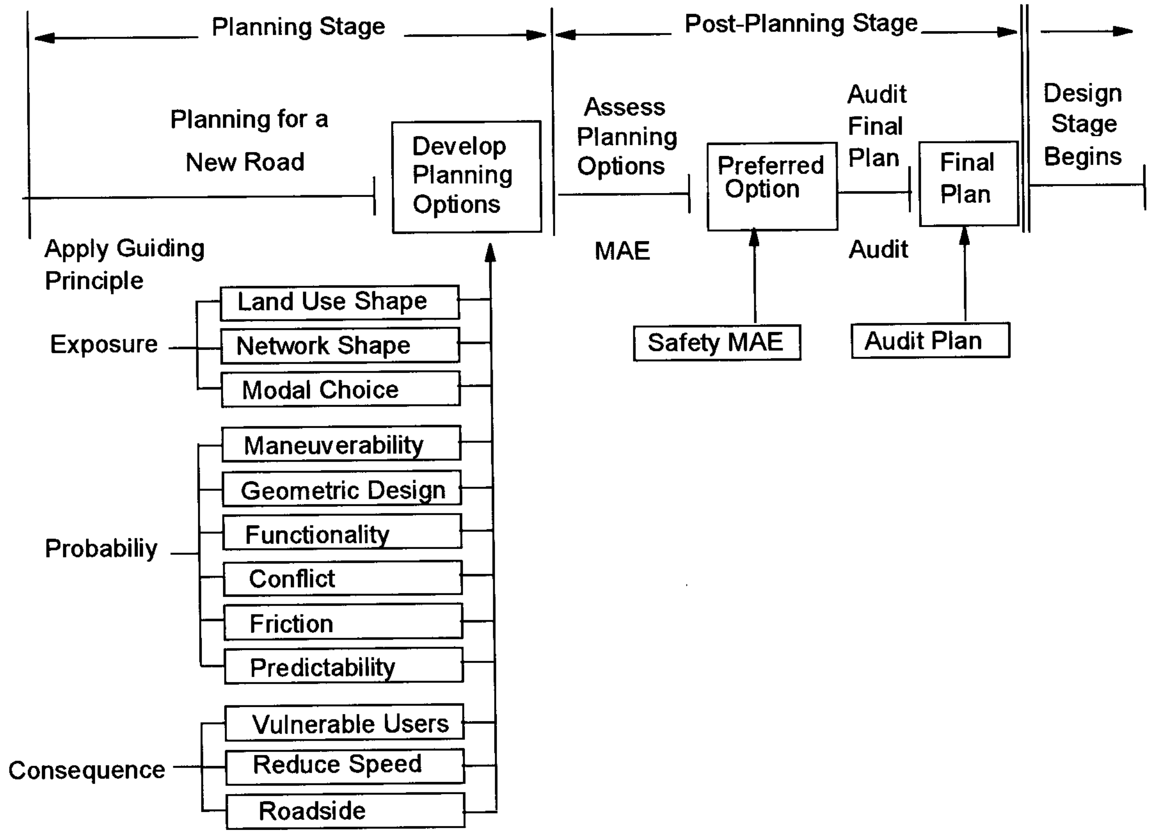

Figure 7.1: Proposed Framework for Proactive Road Safety Planning

In order to test the validity of the methodology and the suitability of the framework for road safety planning, a case study was conducted using a highway-planning project located in the Lower Mainland of British Columbia. Many of the guiding principles associated with exposure, probability and consequence were applied to the Cape Horn Area Network Study and the results indicated that the proposed methodology and framework was effective in isolating safety concerns and explicitly accommodating road safety requirements.

7.1.4 Collision Prediction Models for Road Safety Management

Chapter 6 describes the development of collision prediction models (CPM) for proactive road safety management. Historically, the usefulness and application of CPMs has been very limited for several reasons. First, to be effective, the CPM should be relevant and reflect local conditions and thus, a CPM developed in another jurisdiction and under different conditions (different road classifications, traffic characteristics, collision reporting practices, etc.) may not yield accurate results locally. Secondly, a CPM should be somewhat current to reflect safety advancements such as the use of airbags or better road design standards. Third, CPMs developed some time ago may not reflect the current knowledge and techniques used for modeling. Finally, there has been a problem with a practitioner's understanding and ability to use CPMs to improve the management of road safety.

A basic CPM was developed that predicts the frequency of collisions based on the traffic volume and segment length for rural, 2-lane highways in BC. With the basic model in place, several other geometric variables, believed to influence the frequency of collision occurrence, were investigated for inclusion in the rural highway prediction model. As a result, a valid CPM was developed using the independent variables of shoulder width, horizontal curve and vertical crest curve (as well as segment length, volume (AADT). The significance of the prediction models was evaluated using the scaled deviance (SD), the χ^2 value, the *Pearson* χ^2 statistic, and the t-ratio test. The model, shown below in equation 7.2, was shown to have a relatively good fit and the value calculated for the t-ratios for all independent variables are significant.

$$Col./3yrs = 0.000433 \times (L \times AADT)^{1.1} \times e^{(-0.2032SW)+(0.0476Hm)+(0.09189VmC))} \quad (7.2)$$

A simple example was provided to demonstrate the usefulness of the developed CPM for proactive road safety management.

7.2 Research Contributions

Claims Data for Road Safety Evaluation

Overall, the results produced by the claims data appear to be very encouraging for use in evaluating road safety. The results suggest that the claims data may be used in place of the deteriorating collision data. It has been demonstrated that claims data can be used to evaluate road safety performance in a similar manner as collision records, as evidenced with the development of a claims prediction model. Demonstrating the usefulness and potential of the claims data highlights the need for ICBC to further develop the quality of the claims data and the access to the claims data for road safety analysis and evaluation.

Development of a Road Safety Risk Index (RSRI)

The development of the RSRI was proven to be valid in terms of producing replicable results from among different observers and when compared with tradition safety measures based on collision records. Due to the quantifiable nature of the RSRI, the results can be used to support road safety analysis and decision making. In particular, locations of high risk can be identified and isolated for road safety improvements. Since the development of the RSRI in 1998, the BC Ministry of Transportation and Highways requests that a drive through safety review based on the RSRI process be completed as one of the inputs to the provincial corridor management planning process.

Framework for Proactive Road Safety Planning

Two specific opportunities were identified in the traditional road planning process that could facilitate the explicit consideration of road safety issues. Traditionally, road safety concerns are rarely explicitly considered in the planning for a new roadway, due primarily to the lack of opportunity within the process. The principle contribution made from this research is the methodology that was developed and proposed to support the framework for proactive road safety planning. This research represents an initial attempt to develop guiding principles that can be used to quantitatively assess safety implications of planning level decisions.

Collision Prediction Models for Safety Management

Although collision prediction models (CPMs) have been available for several years, there has been limited application of among practitioners. The developed model describes how CPMs can be used effectively for proactive road safety management. Two collision prediction models specific for rural, two-lane highways in British Columbia were developed where no other such models existed. The models estimate the collision frequency based on traffic volume, segment length, shoulder width, horizontal curve and degree of vertical crest curve.

8.0 FUTURE RESEARCH

This chapter presents some ideas for potential research that could be undertaken in the future to advance the concepts and initiatives that have been presented in this thesis.

Claims Data for Road Safety Evaluation

1) The claims data used for the development of the prediction model was subjected to considerable quality control and similar quality data may not be readily available within the claims database at ICBC. Therefore, it would be beneficial to investigate the usefulness of raw claims data (i.e., not subjected to the high degree of post-processing).
2) More claim prediction models could be developed to reflect the different types of road features and road classifications. This will be increasingly important if the collision data continues to deteriorate.
3) More research work could be undertaken to support the continuing efforts by ICBC to make claims data more readily available and more valuable for road safety evaluations.

Development of a Road Safety Risk Index

1) The interaction between road design features and the impact on safety is not clearly understood. Thus, it may be meaningful to consider the compounding affects of several road features in assigning the road safety risk. For example, the probability of a off-road incident may be better evaluated by combining the horizontal alignment, the vertical alignment, the location of access points and the super-elevation rather than the horizontal curve alone.
2) Another future research opportunity is to investigate the assignment of weighting factors for specific features that can be shown to have a more significant impact on safety. More research is required to determine if this prioritization of specific features is useful and if so, which features should be given greater importance.

3) A fundamental limitation of the road safety risk index is the subjective nature of the process since any process that relies on a subjective assessment can be susceptible to accuracy problems. Therefore, more research could be completed to establish specific thresholds for the elements of the RSRI that are subjective, attempting to make the process quantifiable.
4) At times, a high-risk roadway feature (or combination of high-risk features) may not result in poor safety performance. Although counter-intuitive, this phenomenon is somewhat common, where a roadway with poor design characteristics exists, but because a driver can identify the potential risk and adapt their behavior by exercising more caution, fewer collisions will result. This condition, which could be researched further, is more applicable to drivers who are familiar with an area or those drivers who can easily recognize locations of potential risk.
5) The RSRI does not provide a sustained opportunity to observe and detect problematic traffic characteristics. Rather, the drive-through safety review is largely limited to an investigation of static road features. More research could be completed to determine how the omission of dynamic traffic characteristics affects the results of the RSRI.

Framework for Proactive Road Safety Planning

1) Many of the processes and guiding principles associated with the proactive road safety framework are qualitatively assessed. More research could be undertaken to make the measurement of these principles more quantitative such that the impact on collision frequency can be established.
2) The scope of planning projects can be highly variable and it is believed that it would be useful to define categories of road planning projects and then establish a unique framework and processes for each category.
3) More research is required in the area of road design consistency. Currently, our knowledge of the impact of design consistency on safety performance is lacking and this information is important in the assessment of many planning decisions.

4) Research is required in the area of road safety auditing to validate and address two issues of concern. First, it is important to ensure consistent results among road safety auditors and secondly, to ensure that the recommendations from safety auditors have a positive impact on safety by reducing the collision frequency.
5) There is also an opportunity to explore the use of traffic micro-simulation models to measure the safety impact of planning decisions. Micro-simulation models have the potential to measure the likelihood of collisions and conflicts, based on driver and vehicle behavior. The usefulness and application of these models at the planning stage should be explored.

Collision Prediction Models for Road Safety Management

1) It became evident through the various case studies, that the most useful tool to assist in making planning decisions was the application of collision prediction models. More effort is required to expand research in this area and develop a complete suite of prediction models to aid in decision making.
2) There are planning tools that may be used to apply the collision prediction models in an automated and systematic manner. One such example is the EMME/2 transportation planning software produced by INRO Consultants Ltd. of Montreal, Quebec. Research could be undertaken to investigate the opportunity and success of including collision prediction models in standard planning software.
3) The transferability of collision prediction models could be investigated further to gain an understanding of how models can be applied in a more universal manner. Transferability of the model validity could be examined between regions and between before and after time periods where the collision data has been shown to deteriorate.

This chapter has provided some preliminary ideas for future research activities that could be undertaken to advance the concepts and initiatives described in this thesis.

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APPENDIX 1

MV104 Form and codes

BRITISH COLUMBIA
MOTOR VEHICLE TRAFFIC ACCIDENT
POLICE INVESTIGATION REPORT

PAGE OF PAGES	ACCIDENT CASE NUMBER	ORIGINAL ACN	POLICE FILE NUMBER
	3015052		

1

DATE OF ACCIDENT Y M D | DATE REPORTED | TIME (24 HOUR) | 1 ☐ NON-REPORTABLE (DO NOT FORWARD TO M.V.D.) | 2 ☐ PROPERTY DAMAGE OVER $1000. | 3 ☐ PERSONAL INJURY | 5 ☐ FATAL | 6 ☐ H & R

1A POLICE 1 ☐ ATTENDED 2 ☐ DID NOT ATTEND | POLICE CODE | POLICE ZONE | LOCATION CODE | CODE 1. PROV. HWY. 2. CITY/MUN. 3. RURAL

CITY, MUNIC., TOWN, DISTRICT, VILLAGE OF: ☐ ORG. ☐ UNORG.

ACCIDENT LOCATION: ON ______ AT ______ OTHER

2 V P C 99 N/A PO | V P C 99 N/A PO

DRIVER LICENCE NO.	EXPIRY	CLASS	PROV. / STATE	DRIVER LICENCE NO.	EXPIRY	CLASS	PROV. / STATE
LAST NAME	FIRST NAMES			LAST NAME	FIRST NAMES		

ADDRESS | ADDRESS

2A BUSINESS ADDRESS | BUSINESS ADDRESS

VOID | VOID

BUSINESS TELEPHONE | BUSINESS TELEPHONE

BIRTHDATE | SEX | HOME TELEPHONE | VEH. COLOR | BIRTHDATE Y M D | SEX | HOME TELEPHONE | VEH. COLOR

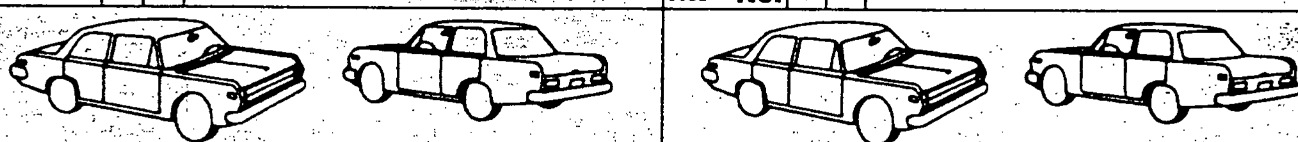
3 VEH. PLATE NO. | PROV. / STATE | YEAR & VEH. MAKE | VEH. STYLE | VEH. PLATE NO. | PROV. / STATE | YEAR & VEH. MAKE | VEH. STYLE

TRAILER / TOWED VEH. PLATE NO. | PROV. / STATE | TRAILER / TOWED VEH. PLATE NO. | PROV. / STATE

4 OWNER NAME AND ADDRESS | OWNER NAME AND ADDRESS

5 NATIONAL SAFETY CODE No. JUR CODE | NATIONAL SAFETY CODE No. JUR CODE

6



DIRECTION OF TRAVEL N E W S P ON: | DIRECTION OF TRAVEL N E W S P ON:

7 SEVERITY | VEH. 1 DAMAGE $ | VEH. 2 DAMAGE $ | SEVERITY

PRIMARY ACCIDENT OCCURRENCE

8 CODE | 1 REAR END | 2 HEAD ON | 3 SIDE SWIPE | 4 BACKING | 5 INTERSECTION | 6 OVERTAKING | 7 RIGHT TURN | 8 RIGHT TURN | 9 RIGHT TURN | 10 RIGHT TURN | 11 LEFT TURN | 12 LEFT TURN | 13 LEFT TURN | 14 OFF ROAD RIGHT | 15 OFF ROAD LEFT | 16 ONE WAY STREET | OTHER ** EXPLAIN IN POLICE COMMENTS

9 VEHICLE TOWED TO / BY | OTHER PROPERTY DAMAGE - DESCRIBE | VEHICLE TOWED TO / BY

☐ I.C.B.C. ☐ OTHER ☐ NONE POLICY NO. COMPANY | ☐ I.C.B.C. ☐ OTHER ☐ NONE POLICY NO. COMPANY

CHARGES DR. 1	SECTION	SHORT TITLE	BTA OR BAC DR. 1	DR. 2	CHARGES DR. 2	SECTION	SHORT TITLE
C M R B			1 / 2	1 / 2	C M R B		
C M R B					C M R B		
C M R B					C M R B		

POLICE COMMENTS Do Not Repeat Information
99 CODE
99 CODE *COPY OF BLANK FORM - NOT TO BE
99 CODE FORWARDED TO ICBC*
99 CODE

TOTAL INJURED | TOTAL KILLED | TOTAL VEHICLES

POLICE COPY

Right margin: 21 22 23 24 25 26 27 28 27A 28A 29 30 31 32 33 34 35 36 37

MV6020A (0298)

NOTE: ALL FIELDS ARE TWO DIGITS EXCEPT 2A WHICH MAY BE THREE

1 **ROAD CLASS**
1_ ONE LANE; 2_ TWO LANE; 3_ THREE LANE; 4_ FOUR LANE; 5_ FIVE LANE; 6_ SIX LANE; 7_ SEVEN LANE
1. UNDIVIDED; 2. DIVIDED; 3. RAMP

1A **TRAFFIC FLOW**
01 ONE-WAY TRAFFIC; 02 TWO-WAY TRAFFIC

2 **ACCIDENT LOCATION**
01 AT INTERSECTION
02 BETWEEN INTERSECTION/EXCHANGES
03 INTERSECTION OF ROAD & DRIVEWAY OR ALLEY
04 BRIDGE
05 FERRY OR DOCK
06 TUNNEL
07 EXIT DECELERATION LANE
08 EXIT RAMP
09 EXIT INTERSECTION
10 ENTRANCE ACCELERATION LANE
11 ENTRANCE RAMP
12 ENTRANCE INTERSECTION
13 OFF HIGHWAY
14 PARKING LOT SINGLE/MULTILEVEL
15 RR CROSSING
16 INDUSTRIAL ROAD
17 TRANSIT EXPRESS LANE

2A **SPEED ZONES**
1_ POSTED SPEED; 2_ ADVISORY; 3_ SPECIAL
1. 10 km/h; 2. 20 km/h; 3. 30 km/h; 4. 40 km/h; 5. 50 km/h; 6. 60 km/h; 7. 70 km/h; 8. 80 km/h; 9. 90 km/h; 10. 100 km/h; 11. 110 km/h

3 **LAND USAGE IN ACCIDENT AREA**
01 SCHOOL/PLAYGROUND
02 URBAN RESIDENTIAL
03 APARTMENT RESIDENTIAL
04 BUSINESS/SHOPPING
05 INDUSTRIAL/MANUFACTURING
06 AGRICULTURAL/UNDEVELOPED
07 RECREATIONAL/PARK/CAMPING
08 RURAL RESIDENTIAL

4 **ROAD TYPE**
01 ASPHALT; 02 GRAVEL; 03 OILED GRAVEL; 04 EARTH; 05 CONCRETE; 06 BRICK/STONE; 07 WOOD

5 **TRAFFIC CONTROL**
01 NONE; 02 STOP SIGN; 03 YIELD SIGN; 04 OFFICER/FLAGMAN/SCHOOL GUARD; 05 RAILROAD CROSSING SIGN; 06 LANE USE/TURN CONTROL SIGN
OR
2_ TRAFFIC SIGNAL; 3_ TRAFFIC SIGNAL WITH ADVANCE FLASHERS; 4_ FLASHING SIGNAL; 5_ LANE USE SIGNAL
AND: 1. RED; 2. YELLOW; 3. GREEN

6 **ROADWAY CHARACTER**
HORIZONTAL: 1_ STRAIGHT; 2_ SINGLE CURVE; 3_ SHARP CURVE; 4_ SWITCHBACK; 5_ WINDING CURVES; 6_ REVERSE CURVE
VERTICAL: 1. FLAT; 2. SOME GRADE; 3. STEEP GRADE; 4. HILLCREST; 5. SAG

7 **ROADWAY SURFACE CONDITION**
01 DRY; 02 WET; 03 MUDDY; 04 SNOW; 05 SLUSH; 06 ICE

8 **WEATHER CONDITIONS**
01 CLEAR; 02 CLOUDY; 03 RAINING; 04 SNOWING/SLEET; 05 HAIL; 06 FOG; 07 SMOG/SMOKE; 08 STRONG WIND

9 **LIGHTING CONDITIONS**
01 DAYLIGHT; 02 DAWN; 03 DUSK; 04 DARK/FULL ILLUM.; 05 DARK/NO ILLUM.; 06 DARK/SOME ILLUM.

10 **INDICATE WHICH VEHICLE OCCUPIED**
01-18 VEHICLE; 20-29 BICYCLE; 30-39 PEDESTRIAN; 90 WITNESS; 99 OTHER**

11 **POSITION IN/ON VEHICLE**
01 DRIVER; 02-07 PASSENGERS; 09-72 PASSENGERS; RIDING/HANGING ON OUTSIDE
3 6 / 2 5 / 1 4 / 7 / 8

12 **SAFETY EQUIPMENT USED**
01 VEH. NOT EQUIPPED; 02 NO RESTRAINT USED; 03 LAP BELT ONLY; 05 LAP & HARNESS; 06 AIR BAG; 07 CHILD RESTRAINT; 08 HELMET; 09 NO HELMET

13 **EJECTION FROM VEHICLE**
01 NOT EJECTED; 02 PARTIALLY EJECTED; 03 EJECTED

14 AGE

15 SEX

16 **LOCATION OF MOST SEVERE INJURY**
01 NO INJURY; 02 HEAD; 03 FACE/NOSE; 04 EYE; 05 NECK; 06 CHEST; 07 BACK; 08 SHOULDER/UPPER ARM; 09 ELBOW/LOWER ARM/HAND; 10 ABDOMEN/PELVIS; 11 HIP/UPPER LEG; 12 KNEE/LOWER LEG/FOOT; 13 ENTIRE BODY

17 **TYPE OF INJURY**
01 NONE; 02 ABRASION; 03 BRUISES; 04 LACERATIONS; 05 BLEEDING; 06 FRACTURE; 07 DISLOCATION; 08 BURNS; 09 AMPUTATIONS; 10 CONCUSSION; 11 DROWNING; 12 WHIPLASH

18 **STATE OF VICTIM CONSCIOUSNESS**
01 APPARENTLY NORMAL; 02 AGITATED; 03 INCOHERENT; 04 SEMI-CONSCIOUS; 05 UNCONSCIOUS; 06 APPARENTLY DEAD; 07 NATURAL CAUSE DEATH

INJURED TAKEN TO 19 BY 20

TYPE OF ACCIDENT COLLISION
01 OTHER MOTOR VEHICLE
02 MOTORCYCLE
03 PEDESTRIAN
04 BICYCLIST
05 ANIMAL
06 RAILROAD TRAIN
07 STREET CAR/TROLLEY COACH
08 ALL-TERRAIN VEHICLE
09 MOPED (UNDER 50cc)
20 LIGHT SUPPORT POLE
21 UTILITY SUPPORT POLE
22 GUARD RAIL/TRAFFIC BARRIER
23 CRASH CUSHION/IMPACT ATTENUATOR
24 SIGN POST
25 TREE
26 BUILDING/WALL
27 CURBING
28 FENCE
29 BRIDGE DECK OR PARAPET
30 RAISED TRAFFIC ISLAND
31 SNOW BANK/DRIFT
32 ROCK FACE
33 DITCH
34 CULVERT
35 FIRE HYDRANT
36 ROCKS OR DEBRIS
40 OVER TURNED
41 FIRE/EXPLOSION
42 SUBMERSION (LAKE, RIVER, SLOUGH)
43 RAN OFF/LEFT ROADWAY
44 RUNAWAY ON GRADE
99 OTHER **EXPLAIN
99 IN POLICE COMMENTS

21 **SECOND EVENT**

THIRD EVENTS
VEH. 1 22
VEH. 2 23

24 **LOCATION OF FIRST CONTACT**
01 ON ROADWAY; 02 OFF ROADWAY

PRE-COLLISION VEHICLE ACTION 1ST EVENT (VEH. 1 25; VEH. 2 26)
01 GOING STRAIGHT AHEAD
02 MAKING RIGHT TURN
03 MAKING LEFT TURN
04 MAKING U-TURN
05 STARTING FROM PARKED POSITION
06 STARTING IN TRAFFIC
07 SLOWING OR STOPPING
08 STOPPED IN TRAFFIC
09 ENTERING PARKED POSITION
10 PARKED LEGALLY
11 PARKED ILLEGALLY
12 AVOIDING OBJECT ON ROAD
13 CHANGING LANES
14 OVERTAKING
15 MERGING
16 BACKING
17 SKIDDING
18 SWERVING
19 SPINNING
20 JACKKNIFING
21 YAW

VEHICLE TYPE (VEH. 1 27; VEH. 2 28)
01 PASSENGER CAR
02 CAR & TRAILER
20 SINGLE UNIT TRK./LT
21 SINGLE UNIT TRK./HY.
30 COMB. UNIT TRK./LT
31 COMB. UNIT TRK./HY.
32 COMB. UNIT TRK./HY.
33 COMB. UNIT TRACTOR/TRL.
34 LOG TRK. & POLE TRL.
35 TOW TRUCK
40 BUS – SCHOOL
41 BUS – LOCAL TRANSIT
42 BUS – INTERCITY
50 MOTORCYCLE
51 MOPED (50cc)
52 BICYCLE
60 TRUCK/CAMPER
61 TRUCK/CAMPER & TRL.
62 MOTOR HOME
63 MOTOR HOME/TRL.
70 TRAILER ONLY
8_ ATV (SEE LIST ON BACK)
9_ SPECIAL (SEE LIST ON BACK)

VEHICLE USE (VEH. 1 27A; VEH. 2 28A)
01 PARKED
02 PERSONAL
03 BUSINESS/COMMERCIAL
05 DRIVER TRAINING FACILITY
05 RECREATIONAL
06 EMERGENCY
07 MILITARY
08 TAXI
09 FARM USE
11 GOVERNMENT
12 TOWING/TOWED
13 STOLEN
2_ DANGEROUS GOODS (SEE LIST ON BACK)

29 **PEDESTRIAN LOCATION**
01 AT INTERSECTION
02 NOT AT INTERSECTION

30 **PEDESTRIAN ACTION**
01 CROSSING WITH SIGNAL
02 CROSSING AGAINST SIGNAL
03 CROSSING, NO SIGNAL, MARKED CROSSWALK
04 CROSSING, NO SIGNAL, NO CROSSWALK
05 WALKING ALONG HIGHWAY WITH TRAFFIC
06 WALKING ALONG HIGHWAY AGAINST TRAFFIC
07 EMERGING FROM FRONT/BEHIND PARKED VEHICLE
08 CHILD GETTING ON/OFF SCHOOL BUS/VEHICLE
09 ADULT GETTING ON/OFF A VEHICLE
10 PUSHING/WORKING ON A CAR
11 WORKING IN ROADWAY
12 PLAYING IN ROADWAY
13 STANDING ON SIDEWALK

APPARENT CONTRIBUTING FACTORS (VEH/DR. 1: 31, 32, 33; VEH/DR. 2: 34, 35, 36)
10 ALCOHOL INVOLVEMENT
11 BACKING UNSAFELY
12 CUTTING IN
13 DRIVING WITHOUT DUE CARE
14 DRIVER INEXPERIENCE
15 DRUGS (ILLEGAL)
16 EXTREME FATIGUE
17 FAILING TO SIGNAL
18 FAILING TO YIELD RIGHT-OF-WAY
19 FELL ASLEEP
20 FOLLOWING TOO CLOSELY
21 IMPROPER PASSING
22 ILLNESS (EXPLAIN)
23 SUDDEN LOSS OF CONSCIOUSNESS
24 DRIVING ON WRONG SIDE OF ROAD
25 PEDESTRIAN ERROR/CONFUSION
26 PRE-EXISTING PHYSICAL DISABILITY
27 PRESCRIBED MEDICATION
28 ATTEMPT AT SUICIDE (CONFIRMED)
29 IGNORING TRAFFIC CONTROL DEVICE
30 IMPROPER TURNING
31 UNSAFE SPEED
32 IGNORING OFFICER/FLAGMAN/GUARD
33 AVOIDING VEH./PED./CYCLIST
40 ACCELERATOR DEFECTIVE
41 BRAKES DEFECTIVE
42 HEADLIGHTS DEFECTIVE/OUT
43 BRAKE LIGHTS OUT
44 TURN SIGNALS DEFECTIVE
45 OVERSIZE VEHICLE
46 STEERING FAILURE
47 TIRES – FAILURE/INADEQUATE
48 TOW HITCH FAILURE
49 DRIVERLESS VEHICLE
50 WINDSHIELD DEFECTIVE
51 ENGINE FAILURE
52 SUSPENSION DEFECT
53 RESTRAINT SYSTEM
54 INSECURE LOAD
55 DANGEROUS GOODS
60 VEHICLE MODIFICATION **EXPLAIN
61 GLARE – ARTIFICIAL
62 GLARE – SUNLIGHT
63 OBSTRUCTION/DEBRIS ON ROAD
64 PAVEMENT SURFACE DEFECTIVE
65 VISIBILITY IMPAIRED
66 WEATHER
67 ROAD MAINTENANCE/CONSTRUCTION
68 PREVIOUS TRAFFIC ACCIDENT
69 SIGN OBSTRUCTION
70 DOMESTIC ANIMAL
71 WILD ANIMAL
72 INSUFFICIENT TRAFFIC CONTROL
73 ROAD/INTERSECTION DESIGN
74 ROADSIDE HAZARD
99 OTHER **EXPLAIN IN POLICE COMMENTS

37 **SPECIAL STUDY**
IF APPLICABLE – PLACE DECAL HERE

IF DATA NOT PRESENT USE CODE 99 AND EXPLAIN IN POLICE COMMENTS