APPENDIX 2F – Evaluation of Road Improvement Program

Road Improvement Program

Program Evaluation Report:

Road Improvement Program
Insurance Corporation of BC

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December 2001

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EXECUTIVE SUMMARY

ES.1 The Need to Evaluate

It is very important to determine whether the goals and objectives of the Road Improvement Program are satisfied and to justify ICBC's expenditure on road improvements. A regular program evaluation can be conducted to determine the cost-effectiveness of road safety investments and to determine whether the program objectives are met. An accurate evaluation will ensure the effective use of road improvement funding, thereby guaranteeing the continued success of the program. This is the latest program evaluation, reporting on the effectiveness of a sample of road improvement projects that were completed in 1998 and 1999.

The importance of a formal and technically robust program evaluation cannot be understated. Professional judgment or opinion is not adequate to prove the effectiveness of road safety improvements. Moreover, justification can only be achieved by conducting a rigorous program evaluation that is based on empirical evidence. Several threats to the validity of an accurate program evaluation are described in this report, including 1) history, 2) maturation, and 3) regression artifacts. There are proven techniques that are used to accommodate these potential difficulties in the program evaluation procedures.

ES.2 Reliable Program Evaluation Methodology

A methodology was developed for evaluating ICBC's Road Improvement Program in 1995. The 1995 method proposed the use reference groups to adjust for the regression to the mean bias and to adjust for history and maturation if the size of the reference group was large enough. Otherwise, data from a comparison group should be used in conjunction with the reference group. The 1995 study clearly demonstrated the need to consider the random nature of collisions when conducting a formal program evaluation and recommended an Empirical Bayes approach. The methodology reported in 1995 was useful for conducting reliable economic evaluations of safety improvement projects.

Since the preparation of the 1995 program evaluation study, there have been several advances in road safety research. The use of collision prediction models is now becoming a standard safety practice. Methods for assessing the reliability of evaluation results are also more frequently used. In addition, a better understanding of the evaluation techniques has been achieved. As a result of these advances, the 1995 evaluation methodology was updated for this 2001 program evaluation report.

The updated program evaluation methodology developed for this report is based on the use of prediction models. Prediction models are mathematical models that relate the frequency of collisions (or claims) experienced by a road entity (intersection, segment, etc.) to the various traffic and geometric characteristics of that entity. Prediction models are useful in program evaluations as they provide the ability to estimate the 'normal' or 'expected' safety performance at a location. Prediction models are also very useful when used in combination with existing collision (or claim) history at a site to improve the reliability of the location specific estimate of safety performance.

ES.3 Data Used for Program Evaluation

Several problems associated with police reported collision data were described in this report. These problems prevented the use of police reported collision data for this program evaluation report. As a result, the auto insurance claims data that is available from ICBC was extracted for each improvement site and was used for the analysis. The claims data was demonstrated to be superior with respect to stability of the data source over time. It is noted here, that authors of this report were not involved in the data collection and compilation exercise, but rather received the claims data from ICBC staff members.

Although 207 road improvement projects were funded in the years 1998 and 1999, it was not possible to include all projects in the program evaluation for several reasons. First, it is resource intensive and costly to obtain all the requisite data and as such, a sample of sites would be used to provide an indication of overall program success. Secondly, there must be adequate time to elapse for the pre and post-improvement effectiveness to be measured. Third, at the time of this study, it is very difficult to extract claims data for locations other than intersections (defined by an on-at location reference) and therefore, the sites selected for program evaluation were limited to intersections (i.e., no segment improvement projects were included). Fourth, and due to the reason noted previously, the claim prediction models necessary for program evaluation are, at this time, limited to intersection locations.

As a result of the considerations listed above, road improvement projects that met the following criteria were selected for program evaluation:

1) the location must be an intersection, defined by two crossing streets,
2) a reliable estimate of the traffic volume at each location is available, and
3) the availability of at least 1 year of claims data (pre / post time periods).

At the time of this study, the number of locations meeting these requirements was 31 locations, and represents a total ICBC investment of approximately $1.513 million. The 31 sites represent a sample of the 82 intersection improvement sites in 1998 and 1999, where the total ICBC investment was $6.8 million. It should be noted that ICBC invests in the safety-related component of road improvement projects and therefore this investment is only a portion of the total cost of these projects. This evaluation discusses the benefits of ICBC's specific investment in these projects to ICBC's policyholders. A summary of the 31 sites used in this evaluation is provided in TABLE ES.1.

ES.4 Claim Prediction Model Development

The application and usefulness of prediction models for an effective program was presented in Chapter 3 this report. Data for the traffic volumes and claim frequency was collected for 100 sites and used to develop the claim prediction models. Two claim prediction models were developed; the first model is used to predict the frequency of property damage only (PDO) claims and the second model is used to predict the frequency of severe claims (i.e., injuries and fatalities). The two prediction models that are used for this program evaluation are shown in TABLE ES.2.

TABLE ES.1: Description of Road Improvement Sites Used for 1999 Program Evaluation Report

ID No.	Location Description	Municipality	Project Description	ICBC Investment	Completion Date
1	Route 16 at Highway 97	Prince George	General intersection improvements	$100,000	October 1998
2	64th Avenue at Highway 15 (176th St.)	Surrey	Addition of right turn lane	$30,000	February 1999
3	Burrard Street at 1st Avenue	Vancouver	Addition of left turn bay	$100,000	Oct 1998
4	Burrard Street at Cornwall Avenue	Vancouver	Addition of left turn bay	$100,000	September 1998
5	Knight Street at 57th Avenue	Vancouver	Addition of left turn bay	$100,000	April 1999
6	Dewdney Trunk Road at Lougheed Hwy.	Coquitlam	Lane widening, upgrade sign and signal visibility	$280,000	November 1998
7	Gladwin at Dahlstrom	Abbotsford	Channelization, left turn lane, signal revisions	128,000	January 1999
8	Leon Avenue and Richter Street	Kelowna	Addition of traffic signal	$19,400	December 1998
9	Leon Avenue and Ellis Street	Kelowna	Various, refer to 1997 Hamilton Study	$19,400	December 1998
10	27th Street at 28th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
11	27th Street at 30th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
12	27th Street at 32nd Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
13	27th Street at 39th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
14	Quebec Street at Terminal Avenue	Vancouver	Improve lane marking, signal timing changes	$18,000	May 1998
15	Granville Street at King Edward Ave.	Vancouver	Signal visibility improvement	$6,200	June 1998
16	Nanaimo Street at Kingsway	Vancouver	Signal visibility improvement	$6,200	November 1998
17	Renfrew Street at Hastings Street	Vancouver	Signal visibility improvement	$6,200	July 1998
18	Broadway at Burrard Street	Vancouver	Signal visibility improvement	$6,200	May 1998
19	Fraser Street at King Edward Ave.	Vancouver	Signal visibility improvement	$6,200	July 1998
20	Blundell at Garden City	Richmond	Introduction of left turn arrow	$10,000	July 1998
21	44th Avenue at Arthur Drive	Delta	Realignment of Intersection	$31,000	December 1998
22	Fraser at 41st	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	January 1999
23	Renfrew at Grandview Hwy	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	November 1999
24	Victoria at Kingsway	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	April 1999
25	Victoria at 41st	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	March 1999
26	Victoria at 1st	Vancouver	Pedestrian indicators / control	$60,000	September 1998
27	Highway 16 at Vance / Cowart Rd.	Prince George	Geometric reconstruction	$25,700	October 1999
28	43nd Avenue at 27th Street	Vernon	Signal visibility improvement	$1,250	1999
29	25th Avenue at 34th Street	Vernon	Signal visibility improvement	$1,250	1999
30	30th Avenue at 30th Street	Vernon	Signal visibility improvement	$1,250	1999
31	Knight Street at 41st Avenue	Vancouver	Addition of left turn bay	$175,000	December 1999

TABLE ES.2: Claim Prediction Models
For Program Evaluation

Model No.	Model Formulation		t-ratio	κ	Pearson χ^2 ($<\chi^2$ test)
1	PDO Claims Model: $Claims/3yrs = 0.00002 \times (AADT_{mj\,rd})^{0.9724} \times (AADT_{mn\,rd})^{0.6040}$	a_o	11.72	6.03	88.9
		a_1	10.32		
		a_2	9.24		(117.6)
2	Severe claims Model: $Claims/3yrs = 0.00007 \times (AADT_{mj\,rd})^{1.024} \times (AADT_{mn\,rd})^{0.3576}$	a_o	9.25	4.41	93.0
		a_1	8.4		
		a_2	4.654		(117.6)

The Pearson χ^2 and the t-ratios of the model parameters indicate that the models fit the data very well (the reader can refer to APPENDIX C (Section C.5) for more information concerning the goodness of fit of the developed claim prediction models).

ES.5 Evaluation Results

By using the developed claim prediction models, the effectiveness of the road improvements at each site can be calculated for PDO claims and severe claims using the methodology that is presented Chapter 3. TABLE ES.3 shows the results for the reductions in PDO and severe claims for the 31 sites. The variances in the claim reductions are also provided in TABLE ES.3.

ES.6 Road Improvement Program Effectiveness

The overall effectiveness of the road improvement program can be determined by calculating the benefits of the road improvements in relation to the cost of the improvements. The benefit cost ratio (B/C) and the net present value are the indicators that are used to present these results. The annualized reduction (or increase) in claim frequency is converted to annual benefits (or dis-benefits) using the claim cost shown in TABLE ES.4.

TABLE ES.3: PDO and Injury Reduction Factors For Each Improvement Site

Intersection Number	ICBC Investment	PDO Claims		Injury Claims	
		Reduction*	Variance	Reduction*	Variance
1	$100,000	-63.64%	0.32%	-38.54%	1.27%
2	$30,000	21.82%	3.29%	-15.28%	2.18%
3	$100,000	-16.25%	1.75%	-33.90%	2.59%
4	$100,000	-2.20%	1.89%	-17.08%	2.07%
5	$100,000	-11.34%	0.85%	-20.24%	1.11%
6	$280,000	-34.74%	1.16%	-46.53%	0.87%
7	$128,000	-17.53%	1.49%	-24.01%	1.59%
8	$19,400	-49.76%	4.90%	-11.64%	10.41%
9	$19,400	-7.82%	11.21%	16.05%	28.73%
10	$10,500	-51.30%	8.54%	-55.25%	5.65%
11	$10,500	-7.41%	10.62%	-3.66%	14.19%
12	$10,500	-72.63%	2.07%	-37.53%	6.58%
13	$10,500	-35.86%	5.34%	-23.58%	6.74%
14	$18,000	5.45%	1.46%	-31.76%	1.08%
15	$6,200	4.17%	0.61%	-12.64%	0.90%
16	$6,200	20.80%	1.25%	-15.44%	0.96%
17	$6,200	7.52%	1.14%	26.39%	2.69%
18	$6,200	4.89%	1.44%	-10.19%	2.48%
19	$6,200	-13.66%	1.45%	-10.22%	2.31%
20	$10,000	-9.91%	1.22%	-19.12%	2.06%
21	$31,000	-30.82%	7.68%	-45.75%	6.85%
22	$60,000	38.87%	2.03%	4.37%	2.03%
23	$60,000	35.70%	2.60%	-34.40%	1.55%
24	$60,000	-4.23%	0.75%	-0.77%	1.18%
25	$60,000	34.06%	1.62%	-11.20%	1.52%
26	$60,000	-48.15%	0.78%	-54.97%	0.70%
27	$25,700	-48.25%	3.04%	-53.33%	4.73%
28	$1,250	-44.69%	5.70%	4.02%	21.62%
29	$1,250	-69.25%	4.72%	40.24%	28.24%
30	$1,250	-88.73%	1.23%	-68.62%	4.92%
31	$175,000	-19.72%	1.04%	-34.60%	1.25%
Total	$1,513,250				

* A negative value indicates reduction

TABLE ES.4: Average Claims Cost per Incident

Collision Severity	Claims Cost
Property damage only	$1,400
Severe*	$24,000

* Severe includes collisions that involve injury and fatality.

A discount rate of 11.7% was used in the calculation of the net present value and the benefits cost ratios, a rate that is consistent with ICBC's policy (ICBC (3), 2001). A 5-year payback period was selected to be consistent with ICBC's policy on investment strategies (ICBC (3), 2001). However, the benefit cost ratio for each site was calculated using a 2 year payback period to determine whether the investment met the Road Improvement Program's funding criteria of a return of 2:1 over two years. The results of the analysis are summarized as follows:

1. Overall, the net present value is $13,759,576.27.
2. Overall, the B/C ratio = 10.1:1 over 5 years.
3. Overall, the B/C ratio = 4.7:1 over 2 years (exceeding the 2:1 in 2 year goal).
4. A total of 23 sites (or 77%) exceeded the goal of B/C = 2:1 in 2 years.
5. A total of 27 sites (or 87%) reported a positive NPV (benefits).
6. A total of 26 sites (or 84%) reported a reduction in severe claims.
7. A total of 22 sites (or 71%) reported a reduction in PDO claims.
8. A total of 19 sites (61%) reported a reduction in PDO and severe claims.

The B/C and the variance of the B/C can be used to determine the probability of achieving the 2:1 return on ICBC investment. Chapter 5 provides the details of the reliability of the results. The analysis indicated that there is a 98% probability of achieving or exceeding a 2:1 return on investment, thereby indicating:

1. very strong confidence in the results,
2. proving the effectiveness of the program, and
3. providing the economic justification for road improvement expenditure.

TABLE ES.5: Benefit Cost Ratios For Each Road Improvement Site

Intersection Number	ICBC Investment	2-year Estimated B/C Ratio	5-year Estimated B/C Ratio
1	$100,000	6.71	14.36
2	$30,000	4.35	9.30
3	$100,000	3.73	7.99
4	$100,000	2.05	4.40
5	$100,000	5.31	11.36
6	$280,000	2.75	5.88
7	$128,000	2.76	5.90
8	$19,400	2.01	4.30
9	$19,400	-0.74	-1.58
10	$10,500	9.93	21.26
11	$10,500	0.94	2.02
12	$10,500	11.27	24.13
13	$10,500	8.66	18.54
14	$18,000	24.42	52.27
15	$6,200	53.30	114.08
16	$6,200	52.08	111.47
17	$6,200	-76.56	-163.88
18	$6,200	14.64	31.33
19	$6,200	24.27	51.96
20	$10,000	21.30	45.60
21	$31,000	3.14	6.72
22	$60,000	-3.38	-7.22
23	$60,000	9.42	20.15
24	$60,000	0.74	1.58
25	$60,000	1.57	3.36
26	$60,000	14.99	32.09
27	$25,700	7.94	17.00
28	$1,250	1.96	4.20
29	$1,250	-69.65	-149.09
30	$1,250	147.18	315.03
31	$175,000	5.04	10.78
Overall	**$1,513,250**	4.7	10.1

It is noted that a few sites have a B/C ratio that may seem unusually high (or low). This safety performance will be investigated by Road Improvement Program Engineers and reported at a later date. The authors of this report (the evaluators) are unable, but also should not respond to these anomalies.

1.0 INTRODUCTION

1.1 Background

In 1989, the Insurance Corporation of British Columbia (ICBC) started the Road Improvement Program (RIP). Corporation staff recognized that tangible benefits measured by a reduction in claim costs could be achieved by providing funding for road improvements. At the outset, the new program had very limited funding and targeted only a few locations that offered the greatest potential to reduce claim costs. Due to the success in reducing claim costs, the program has significantly grown since 1989, with a current budget now exceeding $10 Million.

The main objective of the Road Improvement Program is to partner with the road authorities in British Columbia and to invest in road safety improvements with an aim to reduce the frequency and severity of collisions, thereby reducing the insurance claim costs. Often, the partnership starts with an engineering study of a problematic location that is nominated by the road authority, with some input from ICBC staff. The engineering study identifies: 1) the causal factors of the safety problem at the site, 2) the road improvement strategies (countermeasures) and 3) the investment opportunities for ICBC. The investment criterion is calculated based on a target return on investment of 2:1 over two years. In other words, for every dollar invested in a road improvement, ICBC expects to save two dollars in claims costs within two years.

It is very important to determine whether the goals and objectives of the Program are satisfied and to justify ICBC's expenditure on road improvements. Therefore in 1996, the first program evaluation was conducted to determine the cost-effectiveness of road safety investments in the various road improvement projects. There have been two subsequent program evaluations, conducted in 1997 and 1998. This is the latest program evaluation, reporting on the effectiveness of improvement projects completed in 1998 and 1999, and offers a refinement to the evaluation methodology from previous evaluations.

1.2 Program Evaluation Objective

The objective of this study is to conduct a before and after evaluation of the safety performance of a sample of locations improved under the ICBC Road Improvement Program. The study evaluates the effectiveness of the program by quantifying the cost and benefits of each improvement project. A new evaluation methodology will be used, by utilizing and advancing the latest knowledge and experience in the field road safety evaluation, including:

1. The use of auto insurance claim data,
2. The development and application of claim prediction models,
3. Accounting for the change in traffic volume at improvement sites, and
4. The calculation of the uncertainties associated with the results.

1.3 Evolution of the Program Evaluation Methodology

To measure the success of the Road Investment Program and to ensure the proper allocation of available funding, a study was initiated in 1993 to establish a framework for evaluating the economic feasibility of road safety improvement projects. The study described simple methods to quantify the costs and benefits of road improvements. Realizing the limitations of the 1993 study and the need to conduct more accurate and robust economic evaluation of the road improvement program, another study was completed in 1995. The 1995 study demonstrated the need to consider the random nature of collision occurrence when conducting a formal program evaluation. The methodology reported in 1995 was useful for conducting reliable economic evaluations of safety improvement projects.

Since the preparation of the 1995 program evaluation study, there have been several advances in road safety research. The use of collision prediction models is now becoming a standard safety practice. Methods for assessing the reliability of evaluation results are also more frequently used. In addition, a better understanding of the evaluation techniques has been achieved. As a result of these advances, it is now important to update the 1995 methodology and to use this improved methodology for this program evaluation.

1.4 Safety Data: Claims versus Collisions

Police reported collision data is critical to the delivery and evaluation of road safety programs. Unfortunately, in British Columbia the quantity and quality of police reported collision data is susceptible to several problems. These collision data problems can inhibit the ability of safety engineers to identify hazardous locations, to diagnose safety problems, to develop improvement options and to evaluate the effectiveness of safety improvements (i.e., Program Evaluation). As a result, the collision data problems can jeopardize the success and continuance of road safety programs, especially "black-spot" programs, which are dependent on collision records to identify and target high collision locations.

Typical problems with the police reported collision data in British Columbia are described in greater detail in Chapter 4, but are summarized below. The collision data problems 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.

The simple solution to these police reported collision data problems is to have the police attend and report crashes accurately, consistently, and in an efficient manner. Efforts in this direction have taken place since the problems emerged in 1995, but to date little progress has been made to resolve these problems. Therefore, alternative sources of data must be explored and used to undertake road safety program evaluations, thereby reducing the dependency on the provincial collision data.

Since problems with the police reported collision data are not likely to be resolved in the near future, it is necessary to use alternate data to evaluate road safety performance and to complete the program evaluation. An alternate source of data that characterizes the events of a collision are the records available from an auto insurance claim. 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, ICBC handles most auto insurance claims and centrally warehouses all of the claims data. As such, there is a great opportunity to use the claims data for road safety engineering analysis and for program evaluation.

1.5 Program Evaluation Components

An effective and robust program evaluation requires considerable effort. This report provides the details of the various components of the program evaluation process. The components are listed below, together with a short description.

1. Selection of sites for evaluation:

   It is important to randomly select road improvement projects that will be representative of the overall program effectiveness.

2. Data Compilation:

   Obtaining and compiling the various data elements is critically important to the evaluation and requires considerable effort.

3. Formulating the evaluation methodology:

   The evaluation methodology should withstand technical scrutiny and incorporate the latest advances in road safety research.

4. Development of Claim prediction models:

   The development of prediction models is necessary to improve the accuracy and assessment of road safety performance.

5. The computation of the benefit - cost ratio and net present value achieved:

   The overall success of the program's effectiveness is determined and measured by computing the benefit-cost ratio and the net present value.

1.6 Report Structure

Chapter 1 of this report has provided a short introduction, listing the objectives of the report and providing background information. Chapter 2 describes the importance and necessity of effective evaluation of road safety programs; the obstacles to performing program evaluation; and the techniques to ensure effective evaluation are completed. Chapter 3 provides the details of the program evaluation methodology. Chapter 4 provides a discussion of the data elements used in road safety evaluations, including problems with traditional data (i.e., the collision data) and the data that is used for this evaluation (i.e., the auto insurance claims data). Chapter 5 details the results of the program evaluation, listing the reduction in claims, the benefit-cost ratio and the reliability of the results. Chapter 6 is a short chapter describing the supporting processes that are necessary to deliver effective and efficient program evaluations. Chapter 7 concludes the report by providing a short summary and conclusions. A comprehensive reference list and five APPENDICIES are also provided at the end of this report.

2.0 EVALUATING ROAD SAFETY IMPROVEMENT PROGRAMS

2.1 Why Evaluate

Many road safety professionals believe that “common sense” and “practical experience” are sufficient to provide a valid indication of what road safety improvements are effective. At times, there is some opposition with “researchers” or “academics” that are trying to “prove the obvious” and they feel that there is no need to go through all the trouble and expense of evaluating road improvements that “we know” are effective.

However, there are several reasons that make the evaluation of road safety improvements a crucial component of any road safety improvement program. These reasons can be summarized as follows:

1. During times of limited financial resources, it is crucial to ensure that the available funding is directed to programs that have the greatest positive impact on road safety.

2. In the majority of cases, the success of road safety projects is not “self-evident” even to professionals with considerable practical experience. Traffic safety research has definitively indicated that the relationship between various causal factors and collisions is not very clear.

3. There is rarely a simple cause and effect relationship in road safety projects. Usually, several factors that may influence safety in different ways operate simultaneously, such as the changes in traffic volume, driver population, speed, and weather conditions (among others).

Therefore, it is crucial that a formal and technically robust evaluation process be a main component of any road safety improvement program.

2.2 Obstacles to Performing an Effective Evaluation

In the previous section, the importance of performing an effective evaluation of traffic safety programs has been clearly stated. However, this is by no means an easy task, as several factors can contribute to the difficulty of the evaluation. Three factors are detailed below that constitute some of the significant obstacles in performing effective program evaluation.

1. **The availability and quality of collision data:**

   In many cases and as stated in the Introduction, the collision data in British Columbia suffers from several problems related to the timeliness of the data, the quality and reliability of the data, and the stability of the data source.

2. **The nature of collision data:**

   Collisions are rare events that affect the sample size needed for the before-after evaluation. In other words, we may have to wait long time to obtain a statistically significant sample. Collisions are also random events and therefore, the evaluation methodology should account for this randomness.

3. **The need to control for confounding factors:**

   As described earlier, a simple cause and effect relationship is rare in road safety. Usually, several other factors operate simultaneously and may influence road safety performance. Therefore, the effect of these other factors should be separated from the treatment effect.

However, with proper planning and the necessary resources dedicated to the program evaluation, the effect of the obstacles described-above can be significantly reduced or eliminated. A discussion will be provided in Chapter 6 to outline the necessary actions necessary to complete a regular an efficient program evaluation.

2.3 What to Evaluate

The evaluation of road safety improvement programs is usually undertaken by comparing the level of safety before, to the level of safety after the implementation of a specific intervention (improvement). The level of safety performance can be defined in several ways including collisions, claims, conflicts, risk, and so on. For this report, the evaluation is concerned with the analysis of the number of claims, however it is noted that the analytical methods described in this report have most often been associated with collision data but can apply equally to claims [1]. Therefore, evaluating safety improvement programs will be undertaken by comparing the number of claims that have occurred after the implementation of a specific improvement(s) to what would have been the number of claims had the improvement(s) not taken place. The main assumption is that, if nothing else happens, then a change in the number of claims must be attributed to the improvement.

2.4 Threats to the Validity of Effectiveness Evaluations

The evaluation process should ensure that a noted change in the number of claims has been caused by the improvement (countermeasure) and not by other "confounding" factors or causes. If other factors are allowed to contribute to the noted change, then sound conclusions about the effect of the countermeasure cannot be made. Campbell (1975) notes "*if a change or difference occurs, there are rival explanations that could be used to explain away this effect and thus to deny that in this specific experiment any genuine effect of the experimental treatment has been demonstrated*."

While researchers have discussed up to thirteen general classes of these rival explanations, this report will focus on three main factors that are most relevant to road safety evaluation. These factors include history, maturation and regression artifacts.

[1] It is assumed that the theoretical background and the methodology for collision prediction models are equally applicable to claims (see de Leur and Sayed, 2001).

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

Maturation refers to the effect of collision trends over time. For example, a comparison of collisions before and after the implementation of a specific countermeasure may indicate a reduction attributed to the countermeasure. However, a "rival" explanation would be that this reduction is part of a continuing decreasing trend occurring over many years. An example of maturation is illustrated in FIGURE 2.1. The study results (Nichols, 1982) show the effect of seat belt laws on collisions in Victoria, Australia. The study reported reductions of 44% on fatalities and 48% on injuries, attributed to the effect of the safety belt law that took place at the turning of the curve in FIGURE 2.1. However, it is known that in all developed countries, the number of fatalities started to decrease in the seventies perhaps due to improved vehicle design. This trend can be a "rival" explanation to the reduction in collisions (Haight, 1986).

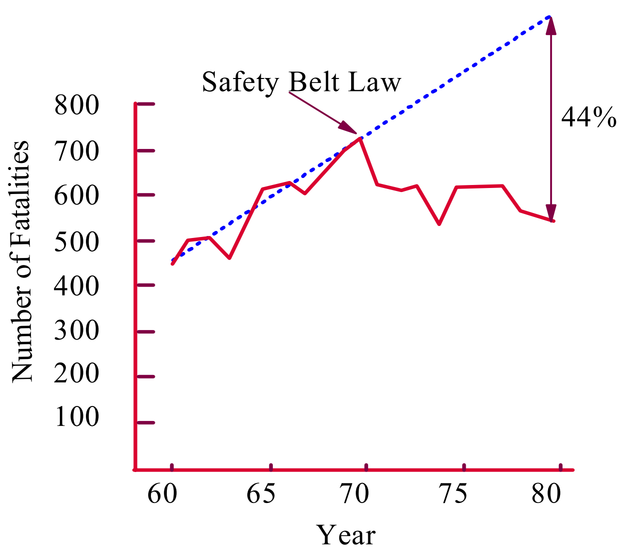

FIGURE 2.1: Misleading Trend Analysis According to Haight (1986)

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

To illustrate the regression to the mean effect (RTM), assume that the points in FIGURE 2.2 represent the number of collisions occurring at a certain site from 1992-1999. Although the average number of collisions is about seven, the individual frequencies range from a low of 2 to a high of 12. Let us assume that the site was selected for treatment in 1995 because of the high collision frequency in the previous two years. Regardless of the effectiveness of the treatment, a subsequent analysis conducted in 1996 would reveal a significant drop in the collision frequency, which often is erroneously attributed to the treatment effect.

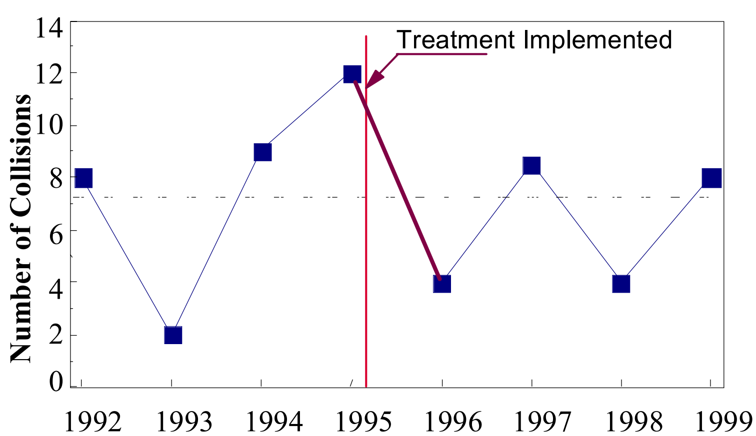

FIGURE 2.2: The RTM Effect

2.5 Techniques to Enhance Effectiveness Evaluations

As noted previously, three main issues represent challenges for accurately estimating the safety benefits of improvement projects: history, maturation and the regression artifacts. The following subsections provide an overview of these issues and the techniques to accommodate the issues in the evaluation methodology.

2.5.1 History and Maturation

To account for the effect of history and maturation for program evaluation, it is usually proposed to use what is known as a "comparison group". In this method, a group of sites considered to be somewhat similar to the ones to be treated are selected and their collision occurrence is observed. By comparing the change in collisions in the comparison group to the change in collisions in the treated sites, the treatment effect can be calculated.

To illustrate the use of the comparison group method, consider the collision data in TABLE 2.1. Assume that the data represents the number of collisions at 10 treatment sites and 10 comparison sites for a similar before and after time period. The data is shown graphically in FIGURE 2.3. If no comparison group is used, then a 10% reduction in collisions will be concluded ((200 – 180) / 200). However, as shown in the figure, it is estimated that the treatment has actually reduced collisions from about 267 collisions to 180 collisions.

TABLE 2.1: Simple Before and After Analysis With A Comparison Group

TIME TREND	TOTAL COLLISIONS	
	Comparison Sites	Treatment Sites
Before	150 (A)	200 (B)
After	200 (C)	180 (D)

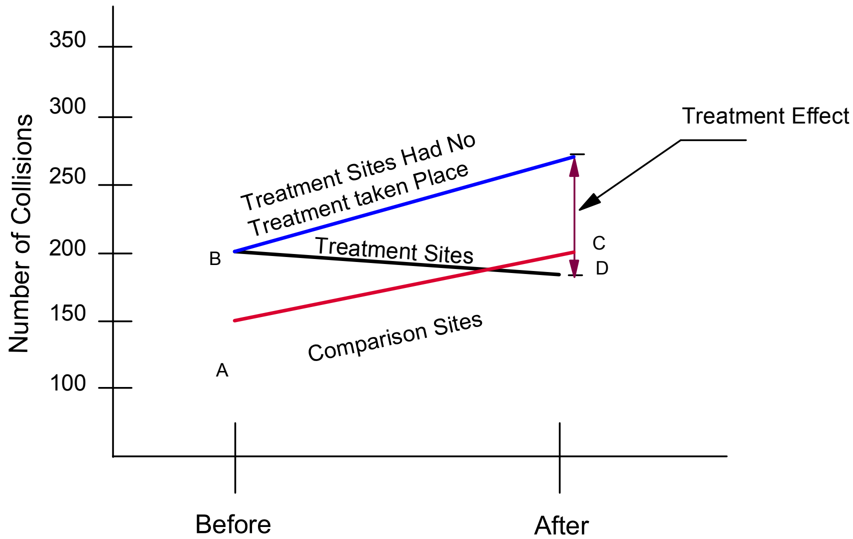

FIGURE 2.3: Before and After Analysis
With a Comparison Group

The treatment effect can be determined by calculating an Odds Ratio (*O.R.*) as shown in equation 2.1. The Odds Ratio represents the change of collisions in the comparison group to the change of collisions in the treatment group. The values A, B, C, and D were defined in TABLE 2.1.

$$O.R. = \frac{A/C}{B/D} = \frac{150/200}{200/180} = 0.675 \qquad (2.1)$$

The value of the *O.R.* minus 1 is used to indicate the magnitude and direction of the road safety treatment effect. For the example provided above, the treatment is calculated to be 32.5% effective in reducing collisions at the site (as shown below in equation 2.2).

$$Effect = O.R. - 1$$

$$Effect = O.R. - 1 = 0.675 - 1.0 = 0.325 \qquad (2.2)$$

2.5.2 The Regression Artifacts

To account for the regression to the mean, a technique known as the Empirical Bayes (EB) technique is used. There are two types of clues to the safety performance of a location: 1) its traffic and road characteristics and 2) its historical collision data (or claim data)[2]. The EB approach makes use of both of these clues to produce a more accurate, location-specific safety estimate. The theoretical information in support of the Empirical Bayes approach is provided in APPENDIX A.

The EB approach is used to refine the estimate of the expected number of collisions at a location by combining the observed number of collisions (at the location) with the predicted number of collisions. The predicted number of collisions is obtained by using information from a reference population. The commonly used Empirical Bayes approach is based on the use of prediction models, developed from the reference population. The development and utilization of prediction models for the EB approach to account for the regression artifacts, is presented in greater detail in Chapter 3 and in APPENDIX C.

[2] It is assumed that the theoretical background and the methodology for collision prediction models are equally applicable to claims (see de Leur and Sayed, 2001).

3.0 PROGRAM EVALUATION METHODOLOGY

3.1 The 1995 Program Evaluation Methodology

As mentioned earlier, a methodology was developed for evaluating ICBC's Road Improvement Program in 1995. The method proposed the use of data from a reference group to adjust for the regression to the mean bias. The same reference group could also adjust for the time trend effect if the size of the reference group was large enough. Otherwise, data from a comparison group should be used in conjunction with the reference group. Thus, two options were available to conduct the program evaluation analysis:

1. Collecting data on a reference group during the "before" period and data on comparison group for both the "before" and "after" periods.
2. Collecting data on a reference group during both the "before" and "after" periods.

If the first option is used, then the Odds Ratio (as described earlier) is calculated as shown in equation (3.1).

$$O.R. = \frac{A / C}{B / D} \qquad (3.1)$$

where:

A = the number of collision (claims) in the comparison group that occurred during the pre-improvement period.

B = the Empirical Bayes' estimate of the number of collisions (claims) in the treatment site(s) had no treatment taken place.

C = the number of collisions (claims) in the comparison group that occurred during the post-improvement period.

D = the number of collisions (claims) in the treatment group that occurred during the post-improvement period.

The quantity *B* is computed by using equation (3.2).

$$B = \sum_{i=1}^{k} \overline{\lambda}_i \, V_i \qquad (3.2)$$

where:

V_i = the traffic volume at site *i.*

$\overline{\lambda}_i$ = the Empirical Bayes estimated collision rate for each site.

k = the number of sites in the treatment group.

If the second option is used then quantities *B* and *D* in Equation (3.1) will remain unchanged. However, quantities *A* and *C* will be defined as:

A = the Empirical Bayes' estimate of collisions (claims) in the reference group that occurred during the "before" period.

C = the observed number of collisions (claims) in the reference group that occurred during the "after" period.

The ratio A/C in this case indicates the time trend effect as defined from the reference group. Quantity *A* will be computed using equation (3.3):

$$A = \sum_{i=1}^{m} \overline{\lambda}_i V_i \qquad (3.3)$$

where:

V_i = the traffic volume at site *i*.

$\overline{\lambda}_i$ = the Empirical Bayes estimated collision rate for each site.

m = the number of sites in the reference group.

The procedure for calculating $\overline{\lambda}_i$ is given in APPENDIX B.

3.2 Update to the 1995 Program Evaluation Methodology

3.2.1 Use of Collision (Claim[3]) Prediction Models

The updated program evaluation methodology developed for this report is based on the use of prediction models. Collision prediction models are mathematical models that relate the collision frequency experienced by a road entity to various traffic and geometric characteristics of that entity. They are developed using certain statistical techniques and have several applications such as evaluating the safety of various road facilities, identifying collision-prone locations, and evaluating the effectiveness of safety improvement measures.

Historically, two statistical modeling methods have been used to develop collision prediction models: 1) conventional linear regression and 2) generalized linear regression. Recently however, generalized linear regression modeling (GLIM) has been used almost exclusively for the development of collision prediction models since it overcomes the shortcomings associated with conventional linear regression for the modeling of collisions. The theoretical background on collision prediction models is given in APPENDIX C.

3.2.2 Estimating the Improvement Effect

The method adopted in this study is based on the EB approach as described by Hauer (Hauer, 1997) and Sayed (Sayed, et al., 1998). The approach uses claim and traffic volume data for a reference group and a comparison group. The role of the comparison group is to represent the time trend from the before to after period. Therefore, it is important that the comparison group represents a random sample and not be selected because of high claim experience. The reference group represents additional information about the treatment site population and is used to account for the regression artifacts. Therefore, the reference group sites must be selected so that they truly represent the potential treatment sites.

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3 As stated previously, it is assumed that the theoretical background and the methodology for collision prediction models are equally applicable to claims (see de Leur and Sayed, 2001)

The safety evaluation is based on two criteria: 1) the reduction in the property damage only claims and 2) the reduction in severe claims (categorized as claims involving fatalities and injuries). Similar to the 1995 methodology, the reduction in the number of claims at the treatment sites can be calculated using the Odds Ratio (O.R.) according to equation (3.4) as follows:

$$O.R. = \frac{A/C}{B/D}$$

$$Treatment\,Effect = O.R. - 1 \tag{3.4}$$

where:

- *A* = the number of claims in the comparison group that occurred during the pre-improvement period.
- *B* = the Empirical Bayes' estimate of the number of claims in the treatment site(s) had no treatment taken place.
- *C* = the number of claims in the comparison group that occurred during the post-improvement period.
- *D* = the number of claims in the treatment group that occurred during the post-improvement period.

It should be noted that all quantities in the Odds Ratio are observed quantities (with assumed Poisson distribution), with the exception of quantity *B,* which is calculated. Therefore, the major work involved in evaluating the benefits of a certain treatment consists of determining the quantity *B.* Unlike the 1995 methodology, this quantity is calculated by utilizing claim prediction models and the Empirical Bayes refinement procedure. Note that the theoretical background associated with the Empirical Bayes technique is provided in APPENDIX A, and the theoretical background associated with claim prediction models is provided in APPENDIX C.

The value B in the Odds Ratio (equation (3.4)) is calculated by using equation (3.5) as follows.

$$B = \sum_{i=1}^{n} (EB_i)_a = \sum_{i=1}^{n} (EB_i)_b \times \frac{E(\Lambda_i)_a}{E(\Lambda_i)_b} \tag{3.5}$$

where:

$(EB_i)_a$ = the Empirical Bayes safety estimate of treated site i in the "after" period had no treatment taken place.

$(EB_i)_b$ = the Empirical Bayes safety estimate of treated site i that occurred in the "before" period.

$E(\Lambda_i)_a$ = the claim frequency given by the claim prediction model for treated site i using its traffic flows in the "after" period.

$E(\Lambda_i)_b$ = the claim frequency given by the claim prediction model for treated site i using its traffic flows in the "before" period.

The Empirical Bayes safety estimate and its variance are calculated using equations (3.6) and (3.7) as follows (and described further in APPENDIX A):

$$EB_i = \left(\frac{E(\Lambda_i)}{\kappa + E(\Lambda_i)} \right) \times \left(\kappa + count_i \right) \tag{3.6}$$

$$Var(EB_i) = \left(\frac{E(\Lambda_i)}{\kappa + E(\Lambda_i)} \right)^2 \times \left(\kappa + count_i \right) \tag{3.7}$$

where:

κ = the negative binomial parameter of the claim prediction model.

$count_i$ = the observed claim frequency in the before period.

To get the expected value and variance of the Odds Ratio, the method of statistical differentials is used as shown in equations (3.8) and (3.9) as follows:

$$\mathrm{E}\{Y\} = Y + \left[\sum_{1}^{n} (\partial^2 Y / \partial X_i^2) \mathrm{VAR}\{X_i\} \right] / 2 \tag{3.8}$$

$$\mathrm{VAR}\{Y\} = \left[\sum_{1}^{n} (\partial Y / \partial X_i)^2 \, \mathrm{VAR}\{X_i\} \right] \tag{3.9}$$

By applying equation (3.8) and equation (3.9) to the Odds Ratio as defined in equation (3.4), the following two equations ((3.10) and (3.11)) for the Odds Ratio can be obtained:

$$E(O.R.) = (\frac{A/C}{B/D}) \times \left(1 + \frac{VarB}{B^2} + \frac{VarC}{C^2} \right) \tag{3.10}$$

$$Var(O.R) = \left(\frac{A/C}{B/D} \right)^2 \times \left(\frac{VarA}{A^2} + \frac{VarB}{B^2} + \frac{VarC}{C^2} + \frac{VarD}{D^2} \right) \tag{3.11}$$

The Odds Ratio and its variance are usually calculated separately for property damage only (PDO) claims and severe claims.

3.2.3 Calculating the Benefit Cost Ratio

Two indicators are used to determine and measure the effectiveness of a road safety improvement project: the net present value and the benefit-cost ratio. The first step in calculating these indicators is to convert the Odds Ratios for PDO and severe claims into an annualized reduction (or increase) in claim frequency. These reductions (or increases) are then converted to annual benefits (or dis-benefits) using the average claim costs.

The expected benefit to cost (B/C) ratio can be calculated by using equation (3.12) as follows:

$$E(B/C) = k_1 \times E(pdo\ claims) + k_2 \times E(injury\, claims) \qquad (3.12)$$

where:

$E(B/C)$ = Expected value of B/C ratio

$pdo.Cost$ = Average PDO claim cost

$inj.Cost$ = Average injury claim cost

t = Payback period (year)

i = Discount rate

$(P/A,i,t)$ = Present worth factor, with a given payback period and discount rate

k_1 $= \dfrac{(pdo.Cost) \times (P/A,i,t)}{Cost_{implementation}}$,

k_2 $= \dfrac{(inj.Cost) \times (P/A,i,t)}{Cost_{implementation}}$

The expected net present value (NPV) is calculated using equation (3.13) as follows:

$$E(NPV) = [k_1 \times E(pdo\ claims) + k_2 \times E(injury\, claims)] - Cost_{implementation} \qquad (3.13)$$

where:

$E(NPV)$ = Expected value of NPV

k_1 $= (pdo.Cost) \times (P/A,i,t)$,

k_2 $= (inj.Cost) \times (P/A,i,t)$

3.3 Advantages of Using Prediction Models in Before and After Studies

Both the 1995 methodology and the updated methodology for the evaluation of the effectiveness of road safety improvements are Empirical Bayes methods. This means that, in addition to attempting to separate the treatment effect from the effects of time trends and causes that are unrelated to the treatment (History and Maturation), these methods also attempt to account for the "regression to the mean" bias described earlier. The major difference between the two methods lies in how each method accounts for the "regression to the mean" bias. The procedure that is proposed in this study for the accommodation of the "regression to the mean" bias is considered more sound than the procedure that was suggested in the 1995 methodology. The main reason for this is described below.

The 1995 method determines an Empirical Bayes safety estimate of the collision *rate* at each intersection belonging to the treatment group. This estimate is obtained by using the "before period" collision count and the "before period" traffic flows at a treated intersection in an Empirical Bayes refinement procedure. The Empirical Bayes refinement procedure refines the mean collision rate of a reference population of similar intersections to yield a location-specific collision rate. The method considers this estimate to be representative of the safety of the treated site during both the "before" period and the "after" period had no treatment taken place. It is multiplied by the traffic flows entering the intersection in the "after period" to determine what would have been the number of collisions at the intersection had no treatment taken place.

The problem with this approach is that collision *rate* cannot be considered to be representative of safety. A lower collision rate at a location does not necessarily mean an improvement in safety. A lower rate could result without any change in collision frequency if there is an increase in traffic flow. A lower rate could result even with an increase in collision frequency if there is a considerable enough increase in traffic flow. In such a case, it offsets the negative effect on collision rate of the higher collision frequency. Also, collision rate cannot be used for safety comparison purposes. A location with a higher collision rate than another similar location does not necessarily mean that it is safer than its counterpart. It could have a higher collision frequency than its counterpart, but the traffic flows using it are also much higher giving it a lower collision rate. On the other hand, the method proposed in this study considers the Empirical Bayes safety estimate of the collision ***frequency*** at an intersection to be representative of safety. This is a more sound approach because it is more logical to judge the safety of a site by the frequency of collisions expected to occur during a certain time period; the higher this number the lower the safety. As described in the new methodology and in APPENDIX C, a collision prediction model is needed before the Empirical Bayes safety estimate of collision frequency can be determined.

4.0 PROGRAM EVALUATION DATA

4.1 Inadequacy of Collision Data

Good quality collision data is critical to the delivery and evaluation of most road safety management programs. However, in many jurisdictions including BC, the collision reporting practices have not been 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 police reported 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 deterioration in the police attended and reported collision frequency on BC Highways is shown below in FIGURE 4.1.

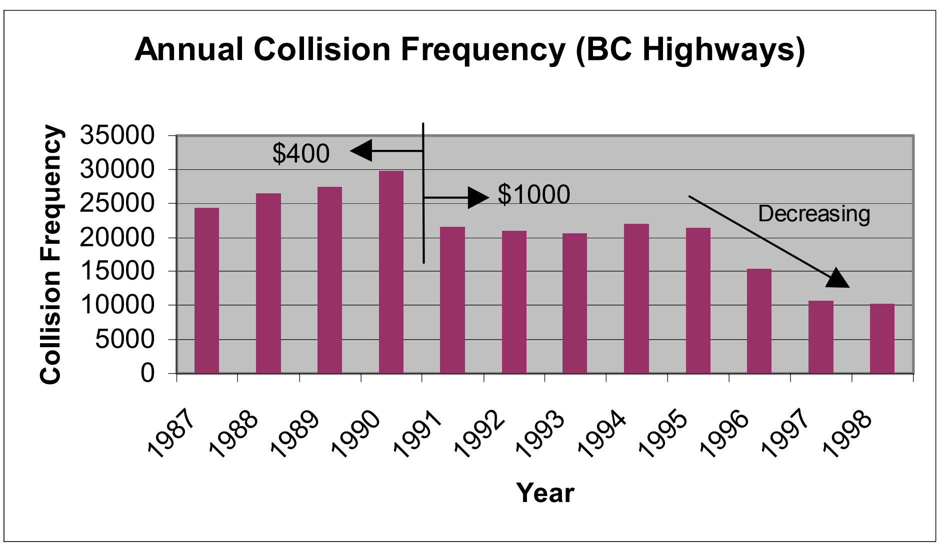


FIGURE 4.1: Change in Collision Reporting Levels on BC Highways

To add to the problem, the reduction in the reporting of collisions is inconsistent around the province. Some areas have not experienced any significant reduction in collision reporting, while in other areas, the reporting frequency has severely diminished. Collision frequencies for two segments of comparable highway were compared; Route 99 the Sea to Sky Highway and the Trans Canada Highway (TCH) in Kootenay Park. The results, shown in FIGURE 4.2 below, indicate that the drop in collision frequency on the highway within Kootenay Park is significant and the drop on the Sea to Sky Highway is minimal, due largely to the local reporting practices.

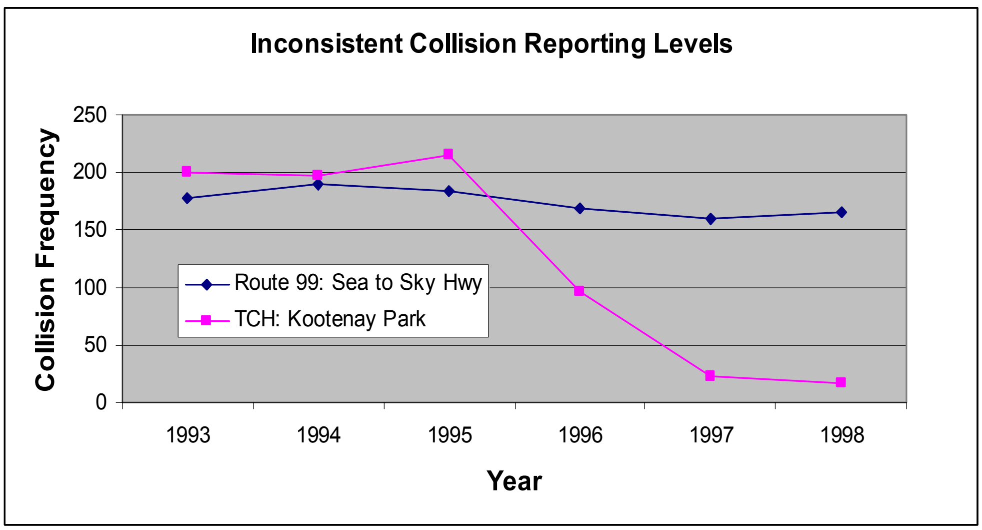


FIGURE 4.2: Inconsistent Collision Reporting Levels

The reliability of collision data is often considered very poor. Even the highest level of collision reporting data (that data collected by enforcement officials) has at times, been found to be unreliable. The sources of unreliability in the data are many, but the principle sources of errors are the mistakes made by officials at the scene, either by a misinterpretation or due to a simple coding error. Errors in judgment and recollection are also made in the self-reporting of collisions (reported by those involved in the collision). More reliability problems are introduced when the data is entered into the data warehouse by clerical staff.

Still another problem associated with the police reported collision data is the accuracy and precision of the data. There are numerous data fields that must be completed on a collision report and many are either subjective or difficult to determine with great accuracy. For example, the location of incidents must be recorded and often the collision has occurred in a remote area where a location reference is difficult. Other data fields, such as the apparent contributing factors to a collision, or determining the pre-collision action, must be subjectively determined based on the judgment of an attending official or assumed to be accurate from a self-reported incident.

The timeliness and availability of police reported 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.

4.2 Claims Data for Program Evaluation

An alternate source of data that characterizes the events of a collision is the records available from an auto insurance claim. 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 BC, ICBC handles and warehouses most auto insurance claims, thereby providing an opportunity to use claims data to evaluate the Road Improvement Program.

Some effort has been made to try and relate auto insurance claims data to police reported collision data. Mercer (Mercer, 1995) developed a series of multipliers to relate the number of claims (incidents) received by ICBC to the number of police reported collisions. The number of incidents is presented in TABLE 4.1, showing that the multiplier increases with a reduction in collision severity, as police are more likely to attend and report a serious collision as opposed to a minor 'fender-bender'. The results also indicate a change over time, reflecting the change in reporting practices.

TABLE 4.1: Multipliers to Relate 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

The results presented in TABLE 4.1 provide clear evidence that the number of claims has not deteriorated over time, in sharp contrast to the collision records. This is an intuitive result, since the reporting of a collision is dependant on police reporting policies, whereas the production of a claim is dependant upon an inevitable result that a motorist will require repairs to his or her vehicle. Thus, the stability of the claims data over time identifies the value of the claim data for use in evaluation of the Road Improvement Program.

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).

It could be argued that the accuracy and reliability of the claims data may not be as good as the police attended and reported incidents. This may be true, especially for the self-reporting of contributing factors such as speeding or alcohol involvement. However, these data elements are more important for engineering diagnostics, including the identification of road related problems and the generation of solutions. Causal factor data is less important for the purposes of program evaluation, favoring the relative stability of the data source from the before period through to the end of the after period. In addition, the accuracy related to the incident location has been known to be problematic for claims data. However for this program evaluation, only signalized intersections were used, partly due to the ability to reliably and accurately extract the claims data for this type of facility, especially in a relative manner from the before to after periods.

Overall, it is concluded that the claims data offers a better source to measure the safety performance of road improvements and to assist in program evaluation.

4.3 Site Selection

4.3.1 Sites Selected for Road Improvement Projects

Although outside the scope of this program evaluation document, it is important to restate the process for which projects are selected for inclusion into ICBC's Road Improvement Program. A rigorous and effective process that identifies the "best" projects (i.e., those that offer the greatest potential for improvement) will ensure that success will be realized upon program evaluation.

Potential sites are nominated by road authority partners (municipalities and the Ministry), for consideration by ICBC staff for funding under the program. For many municipal sites, an engineering study is commissioned and a road safety consultant will investigate the site and determine the potential for investment from ICBC. However, at times the cost of the engineering study may exceed the opportunity cost in collision mitigation for a site (i.e., at sites with very low collision frequency). Other projects, such as those nominated from the British Columbia Ministry of Transportation, are evaluated by Ministry staff, who determine and recommend a contribution by ICBC. Under both scenarios, there is little opportunity to rank or prioritize locations, but rather each site is evaluated independently. In addition, it is not certain that the best techniques are used to identify problematic sites, such that the potential for improvement is clearly evaluated and identified.

Many of the techniques presented in this program evaluation document, such as the used of prediction models and the Empirical Bayes refinement could be used to identify and rank problematic sites. Ideally, it would be beneficial to evaluate a collection of sites by calculating the potential for improvement and then prioritize the locations such that multi-year road safety improvement planning could be completed. More information concerning the process to support program evaluation is provided in Chapter 6 of this report.

4.3.2 Site Selected for Program Evaluation

A sample number of projects funded in the 1998 and 1999 program years were selected for analysis. Projects funded in the year 2000 were excluded due to the limited sample of the "after" claims data available at the time of the study. At least one year of post-improvement data is preferred for a meaningful evaluation. During the two-year study period, investment was provided for a total of 207 projects, representing a total investment of approximately $9.97 million, as summarized in TABLE 4.2.

TABLE 4.2: Number of Projects Funded By ICBC
1998 and 1999 Program Years

PROGRAM YEAR	NUMBER OF PROJECTS	ICBC INVESTMENT
1998	78	$4,573,487
1999	129	$5,394,764
Total	207	$9,968,251

Although the Road Improvement Program comprised of 207 projects over a two-year period, it was not possible to include all projects in the program evaluation for several reasons. First, it is resource intensive and costly to obtain all the data that is required to complete an accurate program evaluation. As such, a sample of sites would be used to provide an indication of overall program success. Secondly, there must be adequate time to elapse for the pre and post-improvement effectiveness to be measured (one-year is a normal minimum). Third, at the time of this study, it is very difficult to extract claims data for locations other than intersections (defined by an on-at location reference) and therefore, the sites selected for program evaluation were limited to intersections (i.e., no segment improvements were included). Fourth, and due to the reason noted previously, the claim prediction models necessary for program evaluation are, at this time, limited to intersection locations.

Several other issues exist concerning the extraction of claims data for program evaluation. First, since a uniform location coding system is not available for claim data, a query routine is developed to identify key words or phrases that match the road names of an intersection. To define a particular location, a minimum of two intersection road names must be provided for a successful query, but it is noted that there may be some inaccuracies in this process. Secondly, the claims records were cross-referenced and incidents involving multiple claims were considered as one collision. Third, comprehensive claims, such as vandalism and theft, were excluded from the claims data. As a result of these considerations, road improvement projects that met the following criteria were selected for program evaluation:

1. The improvement project location must be an intersection and defined by the crossing of two streets,
2. The availability of at least one year of claims data for the pre and post time periods, and
3. A reliable count or an accurate estimate of the requisite traffic volume data at each location was available.

Based on the time-intensive process of generating claims data and the query being limited to intersections (Criteria 1), approximately 40 percent or 82 projects from the total number of projects funded in the two-year study period was randomly selected for further evaluation. From this set of projects, the time period of pre and post implementation was evaluated to meet at least one year (Criteria 2), together with the availability of the traffic volume data (Criteria 3). At the time of this study, the number of locations meeting these data requirements was 31 locations, representing an ICBC investment of approximately $1.513 Million. The 31 sites represent a sample of the 82 intersection improvement sites in 1998 and 1999, where the total ICBC investment was $6.8 million. It should be noted that ICBC invests in the safety-related component of road improvement projects and therefore this investment is only a portion of the total cost of these projects. This evaluation discusses the benefits of ICBC's specific investment in these projects to ICBC's policyholders.

A summary of the 31 improvement sites is shown in TABLE 4.3.

TABLE 4.3: Description of Program Evaluation Sites

ID No.	Location Description	Municipality	Project Description	ICBC Investment	Completion Date
1	Route 16 at Highway 97	Prince George	General intersection improvements	$100,000	October 1998
2	64th Avenue at Highway 15 (176th St.)	Surrey	Addition of right turn lane	$30,000	February 1999
3	Burrard Street at 1st Avenue	Vancouver	Addition of left turn bay	$100,000	Oct 1998
4	Burrard Street at Cornwall Avenue	Vancouver	Addition of left turn bay	$100,000	September 1998
5	Knight Street at 57th Avenue	Vancouver	Addition of left turn bay	$100,000	April 1999
6	Dewdney Trunk Road at Lougheed Hwy.	Coquitlam	Lane widening, upgrade sign and signal visibility	$280,000	November 1998
7	Gladwin at Dahlstrom	Abbotsford	Channelization, left turn lane, signal revisions	$128,000	January 1999
8	Leon Avenue and Richter Street	Kelowna	Addition of traffic signal	$19,400	December 1998
9	Leon Avenue and Ellis Street	Kelowna	Various, refer to 1997 Hamilton Study	$19,400	December 1998
10	27th Street at 28th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
11	27th Street at 30th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
12	27th Street at 32nd Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
13	27th Street at 39th Avenue	Vernon	Left turn slot, intersection realignment, dual primary signal heads/reflective backboards	$10,500	November 1998
14	Quebec Street at Terminal Avenue	Vancouver	Improve lane marking, signal timing changes	$18,000	May 1998
15	Granville Street at King Edward Ave.	Vancouver	Signal visibility improvement	$6,200	June 1998
16	Nanaimo Street at Kingsway	Vancouver	Signal visibility improvement	$6,200	November 1998
17	Renfrew Street at Hastings Street	Vancouver	Signal visibility improvement	$6,200	July 1998
18	Broadway at Burrard Street	Vancouver	Signal visibility improvement	$6,200	May 1998
19	Fraser Street at King Edward Ave.	Vancouver	Signal visibility improvement	$6,200	July 1998
20	Blundell at Garden City	Richmond	Introduction of left turn arrow	$10,000	July 1998
21	44th Avenue at Arthur Drive	Delta	Realignment of Intersection	$31,000	December 1998
22	Fraser at 41st	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	January 1999
23	Renfrew at Grandview Hwy	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	November 1999
24	Victoria at Kingsway	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	April 1999
25	Victoria at 41st	Vancouver	Signal upgrade with new controller and additional left turn arrows	$60,000	March 1999
26	Victoria at 1st	Vancouver	Pedestrian indicators / control	$60,000	September 1998
27	Highway 16 at Vance / Cowart Rd.	Prince George	Geometric reconstruction	$25,700	October 1999
28	43nd Avenue at 27th Street	Vernon	Signal visibility improvement	$1,250	1999
29	25th Avenue at 34th Street	Vernon	Signal visibility improvement	$1,250	1999
30	30th Avenue at 30th Street	Vernon	Signal visibility improvement	$1,250	1999
31	Knight Street at 41st Avenue	Vancouver	Addition of left turn bay	$175,000	December 1999

5.0 PROGRAM EVALUATION RESULTS

5.1 Claim Prediction Models

Two claim prediction models were developed using the GLIM approach as described in APPENDIX C. The first model is used to predict the frequency of property damage only (PDO) claims and the second model is used to predict the severe claim frequency (i.e., injuries or fatalities). Data on traffic volumes and claim frequency was collected for 100 sites and used to develop the models. The two prediction models and the parameters are shown in TABLE 5.1.

TABLE 5.1: Claim Prediction Models

Model No.	Model Formulation		t-ratio	κ	Pearson χ^2 ($<\chi^2$ test)
1	PDO Claims Model:	a_o	11.72		
	$Claims / 3yrs = 0.00002 \times (AADT_{mj\,rd})^{0.9724} \times (AADT_{mn\,rd})^{0.6040}$	a_1	10.32	6.03	88.9
		a_2	9.24		(117.6)
2	Severe claims Model:	a_o	9.25		
	$Claims / 3yrs = 0.00007 \times (AADT_{mj\,rd})^{1.024} \times (AADT_{mn\,rd})^{0.3576}$	a_1	8.4	4.41	93.0
		a_2	4.654		(117.6)

As shown in TABLE 5.1, the Pearson χ^2 and the t-ratios of the model parameters indicate that the models fit the data reasonably well (see APPENDIX C (Section C.5) for more information concerning the goodness of fit of the developed GLIM prediction models).

5.2 Evaluation Results

5.2.1 Reduction in Claims

By using the prediction models, the Odds Ratios, the treatment effects and their variances can be calculated for PDO and severe claims as described in Chapter 3. TABLE 5.2 shows the results for the reductions in PDO and Severe claims for the 31 sites. The variances in the claim reductions are provided in TABLE 5.3.

TABLE 5.2: PDO and Injury Reduction Factors For Each Improvement Site

Intersection Number	ICBC Investment	Reduction* PDO Claims	Reduction* Injury Claims
1	$100,000	-63.64%	-38.54%
2	$30,000	21.82%	-15.28%
3	$100,000	-16.25%	-33.90%
4	$100,000	-2.20%	-17.08%
5	$100,000	-11.34%	-20.24%
6	$280,000	-34.74%	-46.53%
7	$128,000	-17.53%	-24.01%
8	$19,400	-49.76%	-11.64%
9	$19,400	-7.82%	16.05%
10	$10,500	-51.30%	-55.25%
11	$10,500	-7.41%	-3.66%
12	$10,500	-72.63%	-37.53%
13	$10,500	-35.86%	-23.58%
14	$18,000	5.45%	-31.76%
15	$6,200	4.17%	-12.64%
16	$6,200	20.80%	-15.44%
17	$6,200	7.52%	26.39%
18	$6,200	4.89%	-10.19%
19	$6,200	-13.66%	-10.22%
20	$10,000	-9.91%	-19.12%
21	$31,000	-30.82%	-45.75%
22	$60,000	38.87%	4.37%
23	$60,000	35.70%	-34.40%
24	$60,000	-4.23%	-0.77%
25	$60,000	34.06%	-11.20%
26	$60,000	-48.15%	-54.97%
27	$25,700	-48.25%	-53.33%
28	$1,250	-44.69%	4.02%
29	$1,250	-69.25%	40.24%
30	$1,250	-88.73%	-68.62%
31	$175,000	-19.72%	-34.60%
Total	$1,513,250		

* A negative value indicates reduction

TABLE 5.3: Variance in the Claim Reduction For Each Improvement Site

Intersection Number	ICBC Investment	PDO Claims		Injury Claims	
		Reduction*	Variance	Reduction*	Variance
1	$100,000	-63.64%	0.32%	-38.54%	1.27%
2	$30,000	21.82%	3.29%	-15.28%	2.18%
3	$100,000	-16.25%	1.75%	-33.90%	2.59%
4	$100,000	-2.20%	1.89%	-17.08%	2.07%
5	$100,000	-11.34%	0.85%	-20.24%	1.11%
6	$280,000	-34.74%	1.16%	-46.53%	0.87%
7	$128,000	-17.53%	1.49%	-24.01%	1.59%
8	$19,400	-49.76%	4.90%	-11.64%	10.41%
9	$19,400	-7.82%	11.21%	16.05%	28.73%
10	$10,500	-51.30%	8.54%	-55.25%	5.65%
11	$10,500	-7.41%	10.62%	-3.66%	14.19%
12	$10,500	-72.63%	2.07%	-37.53%	6.58%
13	$10,500	-35.86%	5.34%	-23.58%	6.74%
14	$18,000	5.45%	1.46%	-31.76%	1.08%
15	$6,200	4.17%	0.61%	-12.64%	0.90%
16	$6,200	20.80%	1.25%	-15.44%	0.96%
17	$6,200	7.52%	1.14%	26.39%	2.69%
18	$6,200	4.89%	1.44%	-10.19%	2.48%
19	$6,200	-13.66%	1.45%	-10.22%	2.31%
20	$10,000	-9.91%	1.22%	-19.12%	2.06%
21	$31,000	-30.82%	7.68%	-45.75%	6.85%
22	$60,000	38.87%	2.03%	4.37%	2.03%
23	$60,000	35.70%	2.60%	-34.40%	1.55%
24	$60,000	-4.23%	0.75%	-0.77%	1.18%
25	$60,000	34.06%	1.62%	-11.20%	1.52%
26	$60,000	-48.15%	0.78%	-54.97%	0.70%
27	$25,700	-48.25%	3.04%	-53.33%	4.73%
28	$1,250	-44.69%	5.70%	4.02%	21.62%
29	$1,250	-69.25%	4.72%	40.24%	28.24%
30	$1,250	-88.73%	1.23%	-68.62%	4.92%
31	$175,000	-19.72%	1.04%	-34.60%	1.25%
Total	$1,513,250				

* a negative value indicates reduction

5.2.2 The Net Present Value and the Benefit Cost Ratio

The first step in calculating the net present value and the benefit cost ratio is to convert the Odds Ratios to an annualized reduction (or increase) in claims. These reductions (or increases) are then converted to annual benefits (or dis-benefits) using the average claim costs. The average claim costs shown in TABLE 5.4 were used in the calculation of the benefit-cost ratios and are based on the latest values that were available from ICBC.

TABLE 5.4: Average Claims Cost per Incident

Collision Severity	Claims Cost
Property damage only	$1,400
Severe*	$24,000

*Including injury and fatality

A discount rate of 11.7% was used in the calculation of the net present value and the benefits cost ratios, a rate that is consistent with ICBC's policy (ICBC (3), 2001). A 5-year payback period was selected to be consistent with ICBC's policy on investment strategies (ICBC (3), 2001). However, the benefit cost ratio for each site was calculated using a 2 year payback period to determine whether the investment met the Road Improvement Program's funding criteria of a return of 2:1 over two years. The results of the analysis are summarized as follows:

1. Overall, the net present value is $13,759,576.2.
2. Overall, the B/C ratio = 10.1:1 over 5 years.
3. Overall, the B/C ratio = 4.7:1 over 2 years (exceeding the 2:1 in 2 year goal).
4. A total of 23 sites (or 77%) exceeded the goal of B/C = 2:1 in 2 years.
5. A total of 27 sites (or 87%) reported a positive NPV (benefits).
6. A total of 26 sites (or 84%) reported a reduction in severe claims.
7. A total of 22 sites (or 71%) reported a reduction in PDO claims.
8. A total of 19 sites (61%) reported a reduction in PDO and severe claims.

TABLE 5.5 below, shows the B/C ratio that was achieved for each improvement site for both a two and five year time horizon.

TABLE 5.5: Benefit Cost Ratios For Each Road Improvement Site

Intersection Number	ICBC Investment	2-year Estimated B/C Ratio	5-year Estimated B/C Ratio
1	$100,000	6.71	14.36
2	$30,000	4.35	9.30
3	$100,000	3.73	7.99
4	$100,000	2.05	4.40
5	$100,000	5.31	11.36
6	$280,000	2.75	5.88
7	$128,000	2.76	5.90
8	$19,400	2.01	4.30
9	$19,400	-0.74	-1.58
10	$10,500	9.93	21.26
11	$10,500	0.94	2.02
12	$10,500	11.27	24.13
13	$10,500	8.66	18.54
14	$18,000	24.42	52.27
15	$6,200	53.30	114.08
16	$6,200	52.08	111.47
17	$6,200	-76.56	-163.88
18	$6,200	14.64	31.33
19	$6,200	24.27	51.96
20	$10,000	21.30	45.60
21	$31,000	3.14	6.72
22	$60,000	-3.38	-7.22
23	$60,000	9.42	20.15
24	$60,000	0.74	1.58
25	$60,000	1.57	3.36
26	$60,000	14.99	32.09
27	$25,700	7.94	17.00
28	$1,250	1.96	4.20
29	$1,250	-69.65	-149.09
30	$1,250	147.18	315.03
31	$175,000	5.04	10.78
Overall	**$1,513,250**	4.7	10.1

5.2.3 Reliability of the Results

Using the expected value and variance for B/C ratio, the probability density function of the B/C and the NPV can be established. A normal distribution is used to model the NPV and the B/C ratio. For example, by plotting the distribution of the B/C ratio, the probability of achieving a specific B/C ratio can be determined. The distribution is shown in FIGURE 5.1 for the B/C ratio over 2 years.

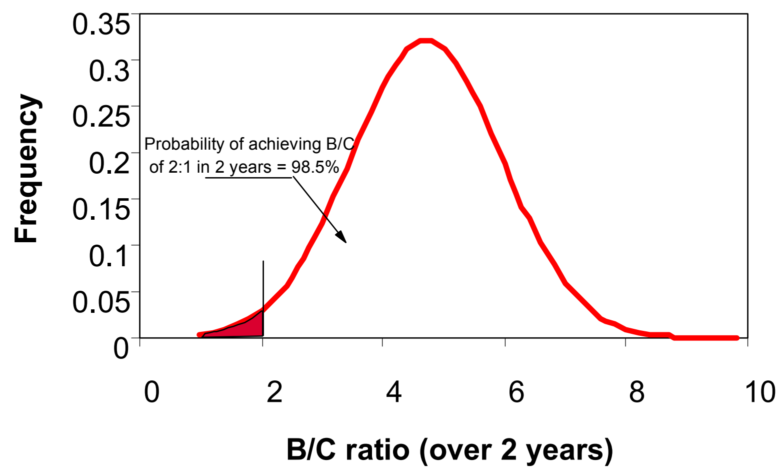


FIGURE 5.1: Probability for B/C Ratio

As shown in FIGURE 5.1, the probability of achieving the 2:1 return on ICBC investment in two years is 98.5%, thereby indicating very strong confidence in the results. The distributions of the NPV and the B/C ratio over 5 years are shown in Appendix D.

6.0 SUPPORTING PROCESS FOR PROGRAM EVALUATION

As stated earlier in this report, it is absolutely critical to accurately evaluate the success of ICBC's Road Improvement Program. An accurate evaluation will ensure the effective use of road improvement funding, thereby guaranteeing the continued success of the program.

There are two distinct components required for the evaluation of the Road Improvement Program (RIP). The first component, as reported in Chapter 3 of this report, is the technical methodology concerning how the evaluation should be conducted, ensuring that the methodology is sound and defendable. The second component relates to the collection and compilation of the data that is necessary for efficient program evaluations. This second component is the focus of this chapter of the report.

6.1 Project Selection

Currently, there are approximately 100 road improvement projects undertaken each year by ICBC's RIP and all of these projects are potentially suitable for evaluation. To support program evaluation, each project should be separated into four general categories according to the type of improvement, including:

1. Rural road improvements,
2. Urban road improvements,
3. Area-wide road improvements, and
4. Pilot project road improvements.

It is recommended that a minimum of one-third (33%) of the total number of projects completed each year be included in the annual program evaluation. Projects should be randomly selected to avoid the potential for selection bias, however, it is noted that the selection of projects may be based on the ability to obtain quality data (collision and/or claim data). A sampling of projects from each category should be included in the evaluation, if the requisite prediction models can be developed and suitable comparison group data can be obtained.

6.2 Data Requirements

There are considerable data requirements necessary for an effective program evaluation and consequently, a considerable effort is required to obtain the data. The requisite data elements are listed below and a data collection form has been developed to collect the requisite data (See APPENDIX E).

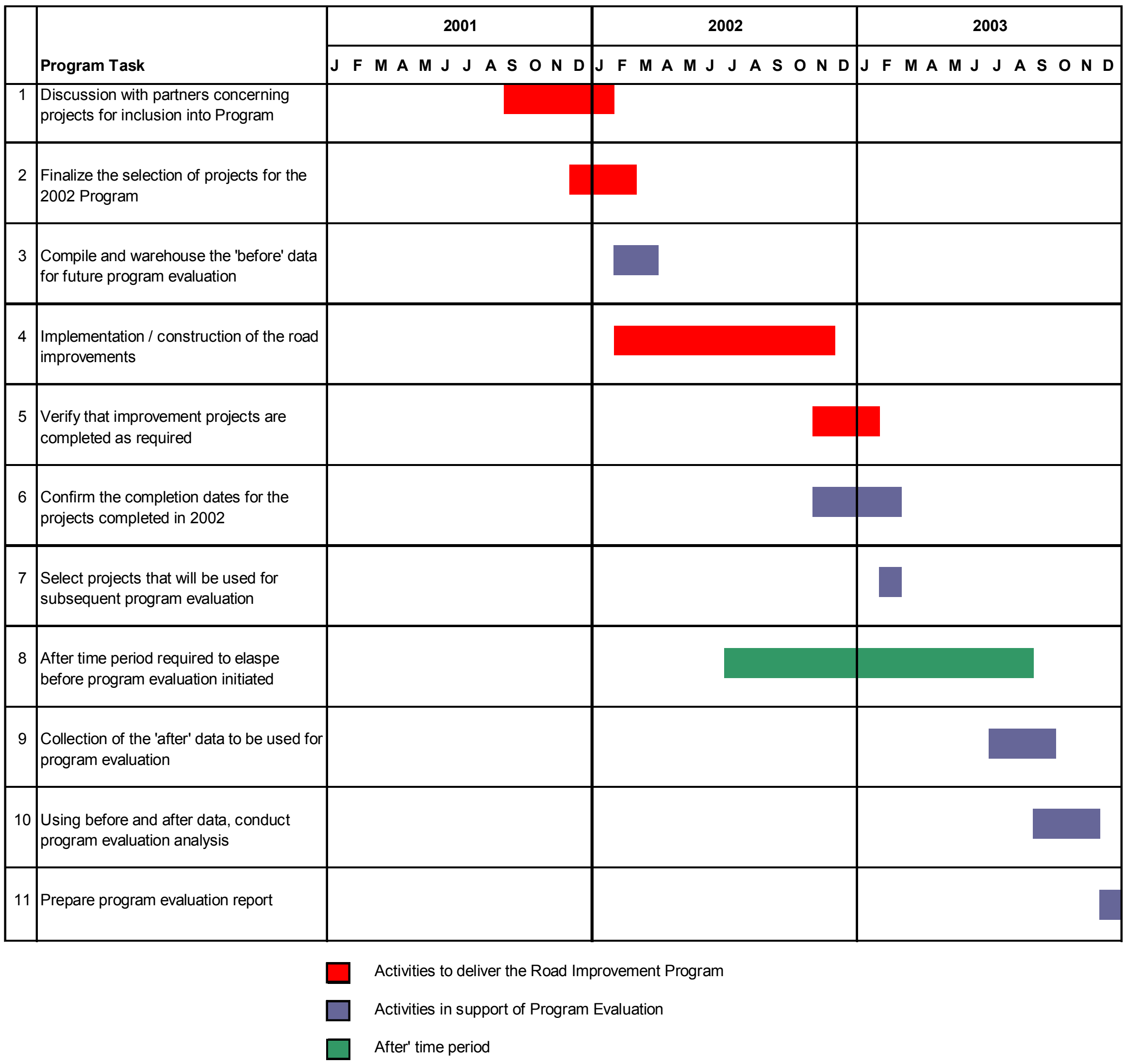
2. Project information (location, location type, contact person, etc.)
3. Before and after collision data,
4. Before and after claims data,
5. Traffic volume during the before and after periods, and
6. The date of countermeasure implementation.

The before data (collisions, claims and volumes) must be obtained and formatted into a standardized form (APPENDIX E) before the funding is released for a project. This data is normally available from the funding contribution report (the B/C report) or from an engineering consultant report of the location. The completion date for each project must be confirmed such that the post-data collection exercise can be initiated. The after data (collisions and volumes) should be obtained with the assistance from the road safety partner and this on-going partnership obligation should be explicitly defined in the contractual agreement. After claims data should be obtained directly from ICBC.

6.3 Program Evaluation Schedule

Efficient program evaluation can be achieved by setting a definitive timetable for the various components of the program evaluation process. The time frame from the date a project is advanced for possible inclusion in the program until sufficient time has elapsed for the 'after' time period can be several years. Uniform and complete data records maintained at specific intervals throughout this long timeframe will ensure efficient program evaluation. A chart, as shown in FIGURE 6.1, has been drafted to highlight the process required to support program evaluation and the associated schedule of activities.

FIGURE 6.1: Example Program Evaluation Schedule for Year 2002



7.0 SUMMARY AND CONCLUSIONS

The goal of this report has been to evaluate the Road Improvement Program and to justify ICBC's expenditure on road improvements. This is the latest program evaluation, reporting on the effectiveness of a sample of road improvement projects completed in 1998 and 1999.

An accurate evaluation will ensure the effective use of road improvement funding, thereby guaranteeing the continued success of the program. The importance of a formal and technically robust program evaluation cannot be understated, as described in Chapter 2. Professional judgment is not adequate to prove the success of road improvements and program justification can only be achieved by conducting a rigorous evaluation based on empirical evidence.

A sound methodology was developed for evaluating ICBC's Road Improvement Program in 1995. However, since the preparation of the 1995 program evaluation study, there have been several advances in road safety research. As a result of these advances, the 1995 evaluation methodology was updated for this 2001 program evaluation report.

The updated program evaluation methodology developed for this report is based on the use of prediction models. Similar to the 1995 methodology, the updated methodology is also an Empirical Bayes approach, accounting for a critically important element in road safety evaluation: the regression to the mean bias. However, the Empirical Bayes procedure proposed in this study is superior due to the utilization of the developed prediction models.

Due to several problems associated with police reported collision data, claims data available from ICBC was extracted for each improvement site and was used for the analysis. The claims data was demonstrated to be superior with respect to stability of the data source over time.

Although over 200 road improvement projects were completed in the years 1998 and 1999, it was not possible to include all projects in the program evaluation for several reasons (as stated in Chapter 4). Only the road improvement projects that met the following criteria were selected for program evaluation:

1) the location must be an intersection, defined by two crossing streets,
2) a reliable estimate of the requisite traffic volume at each location, and
3) the availability of at least 1 year of claims data (pre / post time periods).

At the time of this study, 31 locations met these criteria and were included in the study. These 31 locations represented a total ICBC investment of $1.513 million.

The application and usefulness of prediction models for an effective program evaluation was provided in Chapter 3 of this report. Using claim data from approximately 100 sites, two claim prediction models were developed. By using the developed claim prediction models, the effectiveness of the road improvements for each site can be calculated for PDO claims and severe claims. The results are presented in TABLE 7.1 and show the reductions in the PDO claims and severe claims for the 31 sites evaluated.

The overall effectiveness of the road improvement program is determined by calculating the benefit cost ratio (B/C) and the net present value. The annualized reduction (or increase) in claim frequency is converted to annual benefits (or dis-benefits) using the average cost of claims. The B/C for each road improvement project and for the overall program (based on 31 sites evaluated) is presented in TABLE 7.1. A discount rate of 11.7% was used based on ICBC policies.

The B/C and the variance for B/C ratio can be used to determine the probability of achieving the 2:1 return on ICBC investment. The analysis indicated that there is nearly 100% probability of achieving a 2:1 return on investment, thereby:

1) Indicating very strong confidence in the evaluation results,
2) Proving the overall effectiveness of the Road Improvement Program, and
3) Providing the economic justification for road improvement expenditure.

TABLE 7.1: PDO and Injury Reduction Factors, ICBC Savings and B/Cs For Each Improvement Site

Intersection Number	ICBC Investment	Reduction[1] PDO Claims	Reduction[1] Injury Claims	2-year Est. B/C Ratio[2]	5-year Est. B/C Ratio[2]
1	$100,000	-63.64%	-38.54%	6.71	14.36
2	$30,000	21.82%	-15.28%	4.35	9.30
3	$100,000	-16.25%	-33.90%	3.73	7.99
4	$100,000	-2.20%	-17.08%	2.05	4.40
5	$100,000	-11.34%	-20.24%	5.31	11.36
6	$280,000	-34.74%	-46.53%	2.75	5.88
7	$128,000	-17.53%	-24.01%	2.76	5.90
8	$19,400	-49.76%	-11.64%	2.01	4.30
9	$19,400	-7.82%	16.05%	-0.74	-1.58
10	$10,500	-51.30%	-55.25%	9.93	21.26
11	$10,500	-7.41%	-3.66%	0.94	2.02
12	$10,500	-72.63%	-37.53%	11.27	24.13
13	$10,500	-35.86%	-23.58%	8.66	18.54
14	$18,000	5.45%	-31.76%	24.42	52.27
15	$6,200	4.17%	-12.64%	53.30	114.08
16	$6,200	20.80%	-15.44%	52.08	111.47
17	$6,200	7.52%	26.39%	-76.56	-163.88
18	$6,200	4.89%	-10.19%	14.64	31.33
19	$6,200	-13.66%	-10.22%	24.27	51.96
20	$10,000	-9.91%	-19.12%	21.30	45.60
21	$31,000	-30.82%	-45.75%	3.14	6.72
22	$60,000	38.87%	4.37%	-3.38	-7.22
23	$60,000	35.70%	-34.40%	9.42	20.15
24	$60,000	-4.23%	-0.77%	0.74	1.58
25	$60,000	34.06%	-11.20%	1.57	3.36
26	$60,000	-48.15%	-54.97%	14.99	32.09
27	$25,700	-48.25%	-53.33%	7.94	17.00
28	$1,250	-44.69%	4.02%	1.96	4.20
29	$1,250	-69.25%	40.24%	-69.65	-149.09
30	$1,250	-88.73%	-68.62%	147.18	315.03
31	$175,000	-19.72%	-34.60%	5.04	10.78
Total	$1,513,250			4.7	10.1

1. A negative value indicates reduction

2. Estimated B/C ratio over two or five years

The results of this program evaluation, based on a review of the benefit-cost ratios at each road improvement site indicate the following:

1. Overall, the net present value is $13,759,576.2.
2. Overall, the B/C ratio = 10.1:1 over 5 years.
3. Overall, the B/C ratio = 4.7:1 over 2 years (exceeding the 2:1 in 2 year goal).
4. A total of 23 sites (or 77%) exceeded the goal of B/C = 2:1 in 2 years.
5. A total of 27 sites (or 87%) reported a positive NPV (benefits).
6. A total of 26 sites (or 84%) reported a reduction in severe claims.
7. A total of 22 sites (or 71%) reported a reduction in PDO claims.
8. A total of 19 sites (61%) reported a reduction in PDO and severe claims.

Overall, it can be concluded that based on the 31 sites included in this program evaluation, that ICBC road improvement investments are highly cost-effective, where the funding provided for the road improvement is justified by significant reduction in claim and claim costs at improved site.

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APPENDIX A:

IMPROVING LOCATION SPECIFIC PREDICTION: THE EMPIRICAL BAYES REFINEMENT

There are two types of clues to the safety of a location: its traffic and road characteristics, and its historical collision data (Hauer, 1992; Brüde and Larsson, 1988). The Empirical Bayes (EB) approach makes use of both of these clues. The EB approach is used to refine the estimate of the expected number of collisions (or claims)[4] at a location, obtained from a prediction model, by combining it with the observed number of collisions at the location to yield a more accurate, location-specific safety estimate. The details concerning prediction models are provided in APPENDIX C.

This location-specific estimate is designated as the "EB safety estimate" in what follows and represents the best estimate of the safety of a location. The EB safety estimate for any location can be calculated by using the following equation (Hauer, 1992):

$$EB_{safety\ \ estimate} = \alpha \times E(\Lambda) + (1-\alpha) \times count \qquad \text{(A.1)}$$

where:

$$\alpha = \frac{1}{1 + \frac{Var(E(\Lambda))}{E(\Lambda)}} \qquad \text{(A.2)}$$

$count$ = observed number of collisions

$E(\Lambda)$ = predicted number of collisions, estimated by the prediction model

$Var(E(\Lambda))$ = variance of the GLIM estimate

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[4] It is assumed that the theoretical background and the methodology for collision prediction models are equally applicable to claims (see deLeur and Sayed, 2001).

Since $Var(E(\Lambda)) = \frac{E(\Lambda)^2}{\kappa}$, equation (A.1) can be rearranged to yield equation (A.3) as follows:

$$EB_{safety\ estimate} = \left(\frac{E(\Lambda)}{\kappa + E(\Lambda)}\right) \times (\kappa + count) \qquad \text{(A.3)}$$

The variance of the EB safety estimate can also be calculated using equation (A.4) as follows:

$$Var(EB_{safety\ estimate}) = \left(\frac{E(\Lambda)}{\kappa + E(\Lambda)}\right)^2 \times (\kappa + count) \qquad \text{(A.4)}$$

APPENDIX B:

THE EMPIRICAL BAYES' ESTIMATED COLLISION RATE (1995 METHODOLOGY)

For a group of *k* sites, each with a collision count of N_i and a traffic volume of V_i, the following steps should be followed to estimate the expected collision rate at a site $(\bar{\lambda}_i)$:

1. Calculate the collision rate at each improvement site (λ_i) using equation (B.1) as follows:

$$\lambda_i = \frac{N_i}{V_i} \qquad \text{(B.1)}$$

2. Calculate the sample mean collision rate and its variance by using equations (B.2) and (B.3) as follows:

$$VAR(\bar{\lambda}) = \frac{1}{k-1}\sum_{i=1}^{k}\left(\frac{N_i}{V_i} - \bar{\lambda}\right)^2 \qquad \text{(B.2)}$$

$$\bar{\lambda} = \frac{1}{k}\sum_{i=1}^{k}\frac{N_i}{V_i} \qquad \text{(B.3)}$$

3. Estimate the parameters of the prior gamma distribution (α, β). There are two main methods for this estimation. The simpler is the method of moments estimates (MME), where (α, β) are chosen so that the mean and variance associated with the gamma distribution are equal to the mean and variance of the sample. Thus (α, β) can be calculated using equations (B.4) and (B.5).

$$\beta = \frac{\overline{V}.\overline{\lambda}}{\overline{V}.VAR(\lambda) - \overline{\lambda}} \qquad (B.4)$$

$$\alpha = \beta\overline{\lambda} \qquad (B.5)$$

where:

$\overline{V}$ = the harmonic mean of the normalized traffic volumes.

In the other method, which is more accurate than the MME, the parameters of the gamma distribution $(\alpha,\ \beta)$ are chosen to maximize the following:

$$\Phi(\lambda_1, \lambda_2, ..., \lambda_k | \alpha, \beta) = \prod_{i=1}^{k} \frac{\beta^{\alpha}}{\Gamma(\alpha)} \lambda_i^{\alpha-1} e^{-\beta\lambda_i} \qquad (B.6)$$

where:

Φ = the maximum likelihood function that is associated with the sample data.

4. Update the prior parameters of the gamma distribution with the site-specific collision data to obtain the posterior parameters, using equations (B.7) and (B.8) as follows:

$$\alpha_i = \alpha + N_i \qquad (B.7)$$

$$\beta_i = \beta + V_i \qquad (B.8)$$

5. The Empirical Bayes' estimate of the site collision rate can be calculated using equation (B.9) as follows:

$$\overline{\lambda}_i = \frac{\alpha_i}{\beta_i} \qquad (B.9)$$

APPENDIX C

COLLISION (CLAIM[5]) PREDICTION MODELS

C.1 Background

Historically, two statistical modeling methods have been used to develop collision prediction models: conventional linear regression and generalized linear regression. Recently however, generalized linear regression modeling (GLIM) has been used almost exclusively for the development of collision prediction models. Several researchers (e.g. Jovanis and Chang 1986, Hauer et al. 1988, Miaou and Lum 1993) have demonstrated the inappropriateness of conventional linear regression for modeling discrete, non-negative, and rare events such as traffic collisions. These researchers demonstrated that the standard conditions under which conventional linear regression is appropriate (Normal model errors, constant error variance, and the existence of a linear relationship between the response and explanatory variables) and cannot be assumed to exist when modeling the occurrence of traffic collisions.

Currently, most safety researchers adopt a non-linear model form and a Poisson or negative binomial error structure in the development of collision prediction models. GLIM statistical software packages are used for the development of these models since they can be used for modeling data that follow a wide range of probability distributions that belong to the exponential family such as the Normal, Poisson, binomial, negative binomial, gamma, and many others. These computer packages also allow the flexibility of using several non-linear model forms that can be converted into linear forms through the use of several built-in link functions. The road safety literature is rich with collision prediction models developed by Poisson or negative binomial regression, and models exist for various types of road facilities in urban and rural settings.

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5 It is assumed that the theoretical background and the methodology for collision prediction models are equally applicable to claims (see deLeur and Sayed, 2001)

C.2 The Generalized Linear Regression Modeling Approach

The GLIM approach used in this study is based on the work of Hauer et al. (1988) and Kulmala (1995). Let Y be a random variable that describes the number of collisions at a given location during a specific time period, and y be the observation of this variable during a period of time. The mean of Y, denoted by Λ, is itself a random variable. Then for $\Lambda = \lambda$, Y is Poisson distributed with parameter λ as shown in equation (C.1):

$$P(Y = y \mid \Lambda = \lambda) = \frac{\lambda^{y} e^{-\lambda}}{y!}; E(Y \mid \Lambda = \lambda) = \lambda; Var(Y \mid \Lambda = \lambda) = \lambda \qquad \text{(C.1)}$$

Since each location has its own regional characteristics with a unique mean collision frequency Λ, Hauer et al. (1988) have shown that for an imaginary group of locations with similar characteristics, Λ follows a gamma distribution with parameters κ and κ / μ, where κ is the shape parameter of the distribution, denoted in equation (C.2):

$$f_{\Lambda}(\lambda) = \frac{(\kappa/\mu)^{\kappa} \lambda^{\kappa-1} e^{-(\kappa/\mu)\lambda}}{\Gamma(\kappa)} \qquad \text{(C.2)}$$

With a mean and variance given by equation (C.3) as follows:

$$E(\Lambda) = \mu; Var(\Lambda) = \frac{\mu^{2}}{\kappa} \qquad \text{(C.3)}$$

Hauer et al. (1988) have also shown that the point probability function of Y is given by the negative binomial distribution with an expected value and variance shown in equation (C.4):

$$E(Y) = \mu;\ Var(Y) = \mu + \frac{\mu^{2}}{\kappa} \qquad \text{(C.4)}$$

As shown in equation (C.4), the variance of the observed number of collisions is generally larger than its expected value. The only exception is when $\kappa \to \infty$, in which case the distribution of Λ is concentrated at a point and the negative binomial distribution becomes identical to the Poisson distribution.

C.3 Model Structure

For Intersections, the model structure most commonly used relates collisions to the product of traffic flows entering the intersection. This type of models has been shown to be more suitable to represent the relationships between collisions and traffic flows at intersections (Hauer et al., 1988). In this model structure, collision 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 (C.5):

$$E(\Lambda) = a_{\circ} V_1^{a_1} V_2^{a_2} \tag{C.5}$$

where:

- $E(\Lambda)$ = expected collision frequency,
- V_1 = major road traffic volume (AADT),
- V_2 = minor road traffic volume (AADT),
- $a_{\circ}, a_1, a_2$ = model parameters.

There are many other variables that can affect collision occurrence such as the road geometric features. Kulmala (1995) proposed to model these additional variables along with traffic flows as sown in equation (C.6) as follows:

$$E(\Lambda) = a_0 \times V_1^{a_1} \times V_2^{a_2} \times e^{\sum b_j x_j} \tag{C.6}$$

where:

- x_j = any additional variable and b_j is a model parameter .

For road sections, the model structure that is commonly used is shown in equation (C.7) as follows:

$$E(\Lambda) = a_0 \times L^{a_1} \times V^{a_2} \times e^{\sum_{j=1}^{m} b_j x_j} \tag{C.7}$$

where:

$E(\Lambda)$ = predicted collision frequency

L = segment length

V = segment traffic volume (AADT)

x_j = any of variable additional to L and V

a_0, a_1, a_2, b_j = model parameters

C.4 Model Development

The estimation of model parameters is carried out using the GLIM approach implemented by the GLIM 4 statistical software package (Numerical Algorithms Group, 1994). As described earlier, the GLIM approach to modeling traffic collision occurrence assumes an error structure that is Poisson or negative binomial. The decision on whether to use a Poisson or a negative binomial error structure is based on the following methodology. First, the model parameters are estimated based on a Poisson error structure. Then, the dispersion parameter (σ_d) is calculated using equation (C.8) as follows:

$$\sigma_d = \frac{Pearson\chi^2}{n-p} \tag{C.8}$$

where:

n = the number of observations,

p = the number of model parameters, and

$Pearson\chi^2$ = is defined below

$$Pearson\chi^2 = \sum_{i=1}^{n} \frac{[y_i - E(\Lambda_i)]^2}{Var(y_i)} \tag{C.9}$$

where:

y_i = the observed number of collisions on segment i,

$E(\Lambda_i)$ = the predicted number of collisions for segment i as obtained from the collision prediction model, and

$Var(y_i)$ = the variance of the observed number of collisions.

The dispersion parameter, σ_d, is noted by McCullagh and Nelder (1989) to be a useful statistic for assessing the amount of variation in the observed data. If σ_d turns out to be greater than 1.0, then the data have greater dispersion than is explained by the Poisson distribution, and a negative binomial regression model is fitted to the data.

C.5 Model Goodness of Fit

Two statistical measures are used in this study to assess the goodness of fit of the developed GLIM models. The two statistical measures are those cited by McCullagh and Nelder (1989) for assessing a model's goodness of fit and include 1) the $Pearson\chi^2$ statistic, as defined previously in equation (C.9), and 2) the scaled deviance.

The scaled deviance is the likelihood ratio test statistic measuring twice the difference between the log likelihood's of the studied model and the full or saturated model. The full model has as many parameters as there are observations so that the model fits the data perfectly. Therefore, for the full model, which possesses the maximum log likelihood that is achievable under the given data, provides a baseline for assessing the goodness of fit of an intermediate model with p parameters.

McCullagh and Nelder (1989) have shown that if the error structure is Poisson distributed, then the scaled deviance is determined using equation (C.10) as follows:

$$SD = 2\sum_{i=1}^{n} y_i \ln\left(\frac{y_i}{E(\Lambda_i)}\right) \tag{C.10}$$

Alternatively, if the error structure follows the negative binomial distribution, the scaled deviance is given by equation (C.11) as follows:

$$SD = 2\sum_{i=1}^{n}\left[y_i \ln\left(\frac{y_i}{E(\Lambda_i)}\right) - (y_i + \kappa)\ln\left(\frac{y_i + \kappa}{E(\Lambda_i) + \kappa}\right)\right] \tag{C.11}$$

Both the scaled deviance and the $Pearson\chi^2$ have χ^2 distributions for Normal theory linear models, but are asymptotically χ^2 distributed with $n-p$ degrees of freedom for other distributions of the exponential family.

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.

APPENDIX D

THE RELIABILITY OF THE EVALUATION RESULTS

As described in Chapter 5, by using the expected value and variance for the B/C ratio and the NPV, the probability density function of the B/C and the NPV can be established. A normal distribution is used to model the NPV and the B/C ratio, which provides the probability of achieving a specific NPV or B/C ratio. The distribution for the NPV is shown in FIGURE D.1 and the distribution for the B/C ratio over 5 years is shown in Figure D.2.

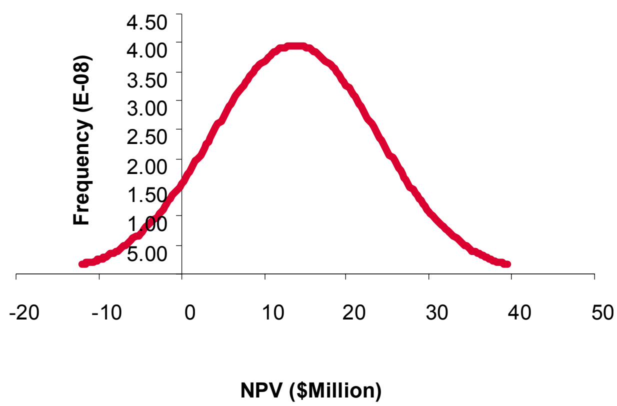

Figure D-1 Distribution of NPV

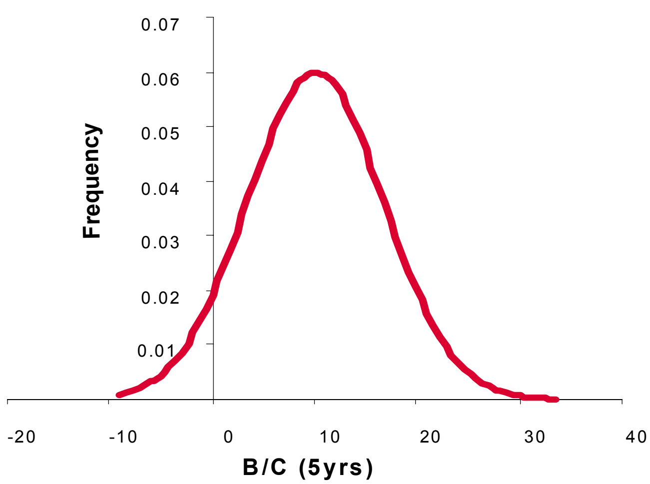

Figure D-2 Distribution of B/C ratio (5yrs)

APPENDIX E:

DATA COLLECTION FORM USED IN SUPPORT OF THE PROGRAM EVALUATION PROCESS

PROJECT SUMMARY FOR	ROAD A AND STREET B
CONTACT PERSON	*Mr. City Engineer*
ROAD AUTHORITY	*Municipality ABC*
COMPLETION DATE	*August 1, 2002*
ICBC INVESTMENT	*$10,000*
TOTAL PROJECT COST	*$90,000*
PROGRAM YEAR	*2001*
ICBC PROJECT NUMBER	*20015001*
PROJECT DESCRIPTION	***Category:*** *Urban Road Improvement (Category 1)*
	Location Type: *Intersection (choose Intersection or Section)*
	Description: *Install left-turn channelization bays for Road 'A' in both the NB and SB directions.*

COLLISION DATA		PRE-IMPROVEMENT	POST-IMPROVEMENT
NUMBER OF COLLISIONS	TOTAL	*8*	*5*
SEVERITY	PDO	*5*	*3*
	INJURY	*3*	*2*
	FATAL	*0*	*0*
NUMBER OF MONTHS (Minimum 12)		*12*	*12*

CLAIMS DATA		PRE-IMPROVEMENT	POST-IMPROVEMENT
NUMBER OF COLLISIONS	TOTAL	*8*	*5*
SEVERITY	PDO	*5*	*3*
	INJURY	*3*	*2*
	FATAL	*0*	*0*
NUMBER OF MONTHS		*12*	*12*

TRAFFIC VOLUMES (AADT)	PRE-IMPROVEMENT	POST-IMPROVEMENT
MAJOR STREET	*10,000*	*12,000*
MINOR STREET	*10,000*	*12,000*
DATE OF COUNT	*September 1, 2000*	*September 1, 2001*

STUDY REFERENCE
"Traffic Operations and Safety Review of Road A and Street B, 1999", prepared by Consultant XYZ

COMMENTS